I557.7
ILLI
No.2
c.3

GRI-92/0391
Illinois Basin Studies 2

Final Report

Gas Potential of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin

Prepared by:
Illinois Basin Consortium
Illinois State Geological Survey
Indiana Geological Survey
Kentucky Geological Survey

Funded by:
Gas Research Institute
Illinois Basin Consortium

Gas Research Institute

Exploration and Production Technology Research Department
January 1994

Digitized by the Internet Archive
in 2018 with funding from
University of Illinois Urbana-Champaign

https://archive.org/details/gaspotentialofne00unse

GRI-92/0391
Illinois Basin Studies 2

FINAL REPORT

GAS POTENTIAL OF THE NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

Edited by Nancy R. Hasenmueller and John B. Comer
Indiana Geological Survey

An Illinois Basin Consortium cooperative research project

The Illinois Basin Consortium consists of the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey

For

GAS RESEARCH INSTITUTE (GRI)
Contract No. 5090-213-1975
David G. Hill, Manager
1994

ILLINOIS STATE LIBRARY

PROJECT MANAGERS

Indiana Geological Survey
John B. Comer
Nancy R. Hasenmueller

PRINCIPAL INVESTIGATORS

Illinois State Geological Survey
Wayne T. Frankie

Kentucky Geological Survey
Terence Hamilton-Smith

INVESTIGATORS

Illinois State Geological Survey
Donald K. Lumm

Indiana Geological Survey
Wesley S. Boberg
Zinta Smidchens

CONTRIBUTORS

Illinois State Geological Survey
Joyce K. Frost

Indiana Geological Survey
Paul N. Irwin
Rea Kersey
Nelson R. Shaffer
Kimberly H. Sowder

Kentucky Geological Survey
Martin C. Noger
Dan Walker

I337.7
ILLI
No.2
c.3

RESEARCH SUMMARY

Title Gas Potential of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin

Contractor An Illinois Basin Consortium (IBC) cooperative research project. The IBC consists of the Illinois State Geological Survey, Indiana Geological Survey, and Kentucky Geological Survey. GRI Contract No. 5090-213-1975.

Project Managers Nancy R. Hasenmueller and John B. Comer, Indiana Geological Survey

Principal Investigators Wayne T. Frankie, Illinois State Geological Survey, and Terence Hamilton-Smith, Kentucky Geological Survey

Report Period May 14, 1990 to July 15, 1992

Objectives To update, compile, review, and interpret all pertinent and available literature, maps, and unpublished data to be used in assessing gas potential of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin; to produce basinwide maps and stratigraphic cross sections relating to the gas potential; to cooperate with interested gas producers and operators to obtain and analyze new core material and other data, particularly from the deeper part of the basin, and from areas where noteworthy gas shows or gas production have been reported from the shale; and to select areas in the basin with the greatest potential for gas production from the shale.

Technical Perspective Commercial gas has been produced from the New Albany Shale from several fields in southern Indiana and western Kentucky. The recently increased gas production in Michigan from the Antrim Shale (Devonian), which is in large part equivalent to the New Albany Shale, has stimulated new interest in the gas potential of the New Albany in the Illinois Basin. The Internal Revenue Code Section 29 production tax credit has stimulated Devonian shale gas production in general. A previous study of the gas potential of the New Albany Shale was part of the Eastern Gas Shales Project, which was sponsored by the U.S. Department of Energy (DOE) from 1976 to 1978. To better characterize and understand the resource potential of the shale, it is necessary to update and evaluate new information obtained since 1978 and interpret pertinent data from the Eastern Gas Shales Project. Information gained from the assimilated data can provide specific guidance for selection of cooperative field research sites in the Illinois Basin; overall, research could result in determining effective ways of producing gas economically from the New Albany Shale.

Results Comprehensive basinwide core location, stratigraphic, and thermal maturity data for the New Albany Shale were compiled. The data were used to produce the following maps: (1) major structural features, (2) core locations, (3) elevation of the top of the New Albany Shale, (4) total thickness of the New Albany Shale, (5) average initial potential (IP) for gas fields producing from the formation, and (6) mean random vitrinite reflectance ($\overline{R}_o$) for New Albany Shale samples. A plate showing regional cross sections was also compiled.

Limited data indicate that gas production is mostly from shale intervals known to have high organic carbon concentrations in the Grassy Creek (Shale), Clegg Creek, and Blocher (Shale) Members of the New Albany Shale and that the produced gas is indigenous. Organic geochemistry data indicate that the New Albany is a rich hydrocarbon source rock and is thermally mature enough to generate oil and associated gas. Production is from fractured zones. The gas is stored as free gas in fractures and also by adsorption on clay and kerogen surfaces. The average IP from 60 fields is 187 thousand cubic feet of gas per day (MCFGPD).

The vitrinite reflectance ($\overline{R}_o$) values for New Albany Shale samples from the commercial gas fields are low (less than 0.70 percent) and considerably below the conventionally accepted range for the main stage of thermal generation of natural gas (0.7 to 2.0 percent). Rock-Eval® T_{MAX} data suggest that some individual shale samples with $\overline{R}_o$ values as low as 0.41 percent are actually mature and that, statistically, generation of associated gas begins

RESEARCH SUMMARY — Continued

at $\overline{R}_o$ values of 0.53 percent. Carbon isotope and composition data indicate that New Albany Shale gas is predominantly thermogenic and associated with oil generation. A number of thermal anomalies, probably reflecting periods of high heat flow, are apparent in the $\overline{R}_o$ data, and they are located mostly along faulted structures in the southern part of the basin. More work is necessary to determine whether anomalous heating events influenced the development of commercial gas reservoirs in these areas.

Technical Approach

Pertinent literature, maps, and unpublished data were compiled, updated, reviewed, and interpreted in the current assessment of the gas potential of the New Albany Shale in the Illinois Basin. Data from more than 5,000 wells in the Illinois Basin, an area covering approximately 60,000 square miles, were used in this study. Six intersecting stratigraphic cross sections were compiled based on geophysical logs. Distinctive lithologic units within the New Albany were correlated on the cross sections. Elevation, thickness, structural elements, core location, gas field location, and vitrinite reflectance maps were made. The elevation and thickness maps were constructed from the New Albany Shale database compiled by the three surveys using the ZYCOR, Inc., contouring program. Some contouring in complexly faulted areas in the southern part of the basin was done by hand. All maps were compared to one another to evaluate the geologic controls on the occurrence of gas.

Implications

Although the New Albany Shale of the Illinois Basin has been estimated to contain approximately 86 trillion cubic feet (TCF) of natural gas in place, the full development of this potentially large domestic resource has not yet occurred. The intent of this study is to reevaluate the potential of the New Albany Shale using an integrated basinwide approach. This study has provided cross sections, maps, and previously unpublished data concerning gas production in a form that can be used by industry for future development of the New Albany Shale.

Because commercial production has been from shale beds having high organic carbon concentrations in the Grassy Creek (Shale), Clegg Creek, and Blocher (Shale) Members, new discoveries will most likely be found in these same units where T_{MAX} is 435°C or greater and $\overline{R}_o$ is 0.53 percent or greater. Both the work in the Appalachian and Michigan Basins and the association of some gas fields in the Illinois Basin with structural features suggest that future discoveries of New Albany Shale gas are most likely to be found along structures, such as faults, folds, and local or regional carbonate build-ups over which the New Albany is draped.

This study has also shown that additional studies are needed to define the true potential of this large natural gas resource. Similarities between the New Albany Shale, the Antrim Shale of the Michigan Basin, and the Ohio Shale of the Appalachian Basin may provide additional incentives to apply technologies that are being successfully employed elsewhere to the Devonian shales in the Illinois Basin.

GRI DISCLAIMER

LEGAL NOTICE: This report was prepared by the Illinois Basin Consortium (IBC), which consists of the Illinois State Geological Survey, Indiana Geological Survey, and Kentucky Geological Survey, as an account of work funded in part by the Gas Research Institute (GRI). Neither GRI, members of GRI, nor any person acting on behalf of either:

a. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

b. Assumes any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

TABLE OF CONTENTS

Abstract 1

Introduction, *by N. R. Hasenmueller, J. B. Comer, W. T. Frankie, and T. Hamilton-Smith* 1

- Purpose of study 1
- Background 3
- Previous studies 3

Data and methods, *by W. T. Frankie, D. K. Lumm, W. S. Boberg, J. B. Comer, and T. Hamilton-Smith* 5

- Introduction 5
- Structural features map 5
- Core location data 5
- Elevation and thickness data 5
- Cross sections 5
- Gas production data 6
- Mineralogical and geochemical data 6
- Source rock data 6

Illinois Basin geologic setting, *by D. K. Lumm, W. T. Frankie, N. R. Hasenmueller, and T. Hamilton-Smith* 9

- Geologic overview 9
- Major structural features 9
- Elevation of the top of the New Albany Shale 12

Stratigraphy, *by N. R. Hasenmueller, W. S. Boberg, D. K. Lumm, W. T. Frankie, T. Hamilton-Smith, and J. B. Comer* 13

- Introduction 13
- Thickness and extent of the New Albany Shale 13
- Bounding stratigraphic units 15
- Correlation of the New Albany Shale with Devonian shales in the Appalachian and Michigan Basins 15
- Members and beds of the New Albany Shale 15
  - Blocher (Shale) Member 17
  - Sylamore Sandstone Member 17
  - Selmier (Shale) Member 17
  - Sweetland Creek Shale Member 18
  - Grassy Creek (Shale) Member 18
  - Morgan Trail Member 18
  - Camp Run Member 19
  - Clegg Creek Member 19
    - Falling Run Bed 19
    - Underwood Bed 19
    - Henryville Bed 19
    - Jacobs Chapel Bed 19
  - Saverton Shale Member 20
  - Louisiana Limestone Member 20
  - Horton Creek Member 20
  - Hannibal (Shale) Member 21
    - Nutwood Bed 21
  - Ellsworth Member 21

Gas production, *by T. Hamilton-Smith, N. R. Hasenmueller, W. S. Boberg, Z. Smidchens, and W. T. Frankie* 23
- Introduction 23
- Kentucky 23
  - Meade County fields 26
  - Meadow Field 27
  - Shrewsbury Consolidated Field 27
  - Other discoveries 28
- Indiana 28
  - Harrison County fields 28
  - Loogootee North Field 29
  - Daviess County fields 32
  - Post-1980 New Albany Shale gas wells 32
- Illinois 32
- Reservoir character 32
  - Introduction 32
  - Gas adsorption 32
  - Fractures 34
  - Water production 34
  - Gas composition 35
  - Stimulation 35
- Devonian shale gas production in the Michigan and Appalachian Basins 37
  - Antrim Shale 37
  - Ohio Shale 39
  - Comparison of the New Albany Shale to the Antrim and Ohio Shales 39

Mineralogy and geochemistry, *by J. K. Frost and N. R. Shaffer* 41
- Introduction 41
- Organic carbon content 41
- Mineralogy 41
- Inorganic geochemistry 44

Source rock potential, *by J. B. Comer, T. Hamilton-Smith, and W. T. Frankie* 47
- Introduction 47
- Organic matter type 47
- Thermal maturity 47
  - Quality of data 47
  - Interpretation 49
  - Relation to gas production 53

Summary and conclusions 55
Acknowledgments 57
References cited 59
Appendix A Selected bibliography 67
Appendix B Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research 70
Appendix C Mean random vitrinite reflectance ($\overline{R}_o$) data for the New Albany Shale in the Illinois Basin 79

ILLUSTRATIONS

Figure 1 Map showing the location of the Illinois Basin, the outcrop of the New Albany Shale (Devonian and Mississippian), and county names in Illinois, Indiana, and Kentucky 2

2 Subsurface reference sections for Illinois, Indiana, and Kentucky 7

3 Map showing major tectonic features in the eastern Midcontinent region of the United States 10

4 Correlation of the New Albany Shale in the Illinois Basin 14

5 Stratigraphic cross sections showing correlations of the Devonian and Mississippian strata from the Michigan and Illinois Basins to the Appalachian Basin 16

6 Graphs showing rock pressure-decline and production-decline curves, Meade County fields, Kentucky, from 1890 to 1921 27

7 Drilling history for the Shrewsbury Consolidated Field area, western Kentucky 27

8 Initial-potential (IP) histogram for New Albany Shale wells in the Shrewsbury Consolidated Field, western Kentucky 28

9 Well-completion history for the New Albany Shale in Indiana 29

10 Zone of gas entry from fractured New Albany Shale in Equitable Resources No. K10001 Hopkins, Hopkins County, Kentucky 35

11 Devonian shale resources and activity in the Appalachian, Illinois, and Michigan Basins 40

12 Mineralogical composition of the New Albany Shale in cores from Indiana Geological Survey SDH No. 273 in Marion County, Indiana, and Energy Resources of Indiana No. 1 Phegley Farms Inc., Sullivan County, Indiana 43

13 Relationship between total sulfur and organic carbon in samples of the New Albany Shale from the Illinois Basin 44

14 Modified van Krevelen diagrams showing Rock-Eval® data for core samples of the New Albany Shale 48

15 Graph of mean random vitrinite reflectance ($\overline{R}_o$) versus present depth of burial 49

16 Graph showing Rock-Eval® T_{MAX} versus mean random vitrinite reflectance ($\overline{R}_o$) 50

17 Graph showing Rock-Eval® T_{MAX} versus depth 52

18 Plot of $\delta^{13}C$ versus $C_1/(C_1$ to $C_5)$ for off-gas from the New Albany Shale core samples 52

19 Graphs showing $\delta^{13}C$ versus depth and composition for off-gas from the New Albany Shale 53

TABLES

Table 1 New Albany Shale gas fields in the Illinois Basin, and locations and average initial potential (IP) of the wells 24

2 Gelatinated nitroglycerine shot stimulation data for the New Albany Shale in the Shrewsbury Consolidated Field, western Kentucky 30

3 Nitrogen-foam fracture stimulation data for the New Albany Shale in the Shrewsbury Consolidated Field, western Kentucky 31

4 Rock pressure and initial-potential (IP) data for Railroaders' Gas Company wells in the New Middletown and Laconia Fields, Harrison County, Indiana 33

5 Composition of gases from the New Albany Shale 36

6 Gelatinated nitroglycerine shot stimulation data for New Albany Shale wells in Indiana 38

7 Nitrogen-foam fracture stimulation data for New Albany Shale wells in Indiana 38

TABLES — Continued

Table 8 Percentage of organic carbon by weight averaged by lithologic unit in samples from Devonian and Mississippian cores in Illinois, Indiana, and western Kentucky 42
9 Rock-Eval® T_{MAX} values for core samples with corresponding mean random vitrinite reflectance ($\overline{R}_o$) data 51
10 Carbon isotope ratios and composition of off-gas from canned cores of the New Albany Shale 54

PLATES (in jacket)

Plate 1 Map showing major structural features of the Illinois Basin
2 Map showing locations of cores of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin
3 Map showing elevation of the top of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin
4 Map showing total thickness of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin
5 Stratigraphic cross sections showing members of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin
6 Map showing average initial potential (IP) for New Albany Shale (Devonian and Mississippian) gas fields in the Illinois Basin
7 Map showing mean random vitrinite reflectance ($\overline{R}_o$) for New Albany Shale (Devonian and Mississippian) in the Illinois Basin

GAS POTENTIAL OF THE NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

ABSTRACT

The project was conducted by the Illinois Basin Consortium (IBC), consisting of the Illinois State Geological Survey, Indiana Geological Survey, and Kentucky Geological Survey, and was partially funded by the Gas Research Institute (GRI). The work consisted of compiling, updating, reviewing, and interpreting all available data relating to gas production and potential for the New Albany Shale in the three-state region.

This project represents a more integrated basinwide approach to determine the gas production potential of the shale in the Illinois Basin than that employed in previous studies. Results of this study include a plate showing basinwide stratigraphic cross sections as well as the following six basinwide maps at a scale of 1:1,000,000: (1) major structural features of the Illinois Basin, (2) locations of cores of the New Albany Shale in the Illinois Basin, (3) elevation of the top of the New Albany Shale in the basin, (4) total thickness of the formation, (5) average initial potential (IP) for New Albany Shale gas fields, and (6) mean random vitrinite reflectance ($\overline{R}_o$) for New Albany Shale samples in the Illinois Basin. Post-1980 gas production data on file at the three surveys, stimulation data for New Albany Shale wells, core location data, and mean random vitrinite reflectance ($\overline{R}_o$) data are also included in the report.

The New Albany Shale is predominantly an organic-rich brownish-black and grayish-black shale that is present in the subsurface throughout the Illinois Basin. It was estimated to contain 86 trillion cubic feet (TCF) of natural gas by the Devonian Shale Task Group of the National Petroleum Council Committee on Unconventional Gas Sources in 1980 and has produced gas for more than 100 years, mostly from western Kentucky and southern Indiana. Where the stratigraphy is known, the gas reservoirs are observed to be in the organic-rich brownish-black shales of the Grassy Creek (Shale), Clegg Creek, and Blocher (Shale) Members. Fractures provide the effective reservoir permeability in some zones and gas is stored both as free gas in fractures and as adsorbed gas on kerogen and clay surfaces. Limited data suggest that some gas fields are associated with faults, folds, and local and regional carbonate buildups over which the New Albany is draped, conditions that would favor the development of fractured reservoirs. The average IP from 60 fields ranged from 1 to 4,400 thousand cubic feet of gas per day (MCFGPD) resulting in a basinwide average IP of 187 MCFGPD.

The $\overline{R}_o$ values for most New Albany Shale samples are low (less than 0.7 percent) and below the conventionally accepted range for the main stage of thermal generation of natural gas (0.7 to 2.0 percent). Rock-Eval® T_{MAX} data indicate that some shale samples with $\overline{R}_o$ values as low as 0.41 percent have begun the natural process of thermal generation of hydrocarbons and that statistically any given organic-rich New Albany Shale sample may begin the generation of associated gas at $\overline{R}_o$ values of about 0.53 percent. Carbon isotope and composition data confirm that New Albany Shale gas is predominantly thermogenic, low maturity, and associated with oil generation. The correlation of geochemical and lithological attributes indicates that the gas is indigenous.

INTRODUCTION

By Nancy R. Hasenmueller, John B. Comer, Wayne T. Frankie, and Terence Hamilton-Smith

Purpose of Study

The total gas content of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin (fig. 1) has been estimated to be 86 trillion cubic feet (TCF) by the Devonian Shale Task Group of the National Petroleum Council Committee on Unconventional Gas Sources (Bookout, 1980). Although the New Albany Shale has produced commercial quantities of gas for more than 100 years from many fields in southern Indiana and western Kentucky, only a small fraction of its potential has been realized. Recently, two incentives have stimulated Devonian shale gas exploration and production in the midwestern and eastern United States: (1) the Internal Revenue Code Section 29 production tax credit, and (2) the increase in gas production in Michigan from the Antrim Shale, which is in large part equivalent to the New Albany Shale. Both have kindled new interest in the potential of the New Albany of the Illinois Basin.

This project was a cooperative research effort of the Illinois Basin Consortium (IBC), which is composed of the Illinois State Geological Survey, Indiana Geological Survey, and Kentucky Geological Survey, and was partially funded by the Gas Research Institute (GRI) under Contract No. 5090-213-1975. The objectives of the project were to update, compile, review, and interpret all pertinent and available literature, maps, and unpublished data to assess the gas potential of the New Albany Shale in the Illinois Basin; to produce basinwide maps and stratigraphic cross sections

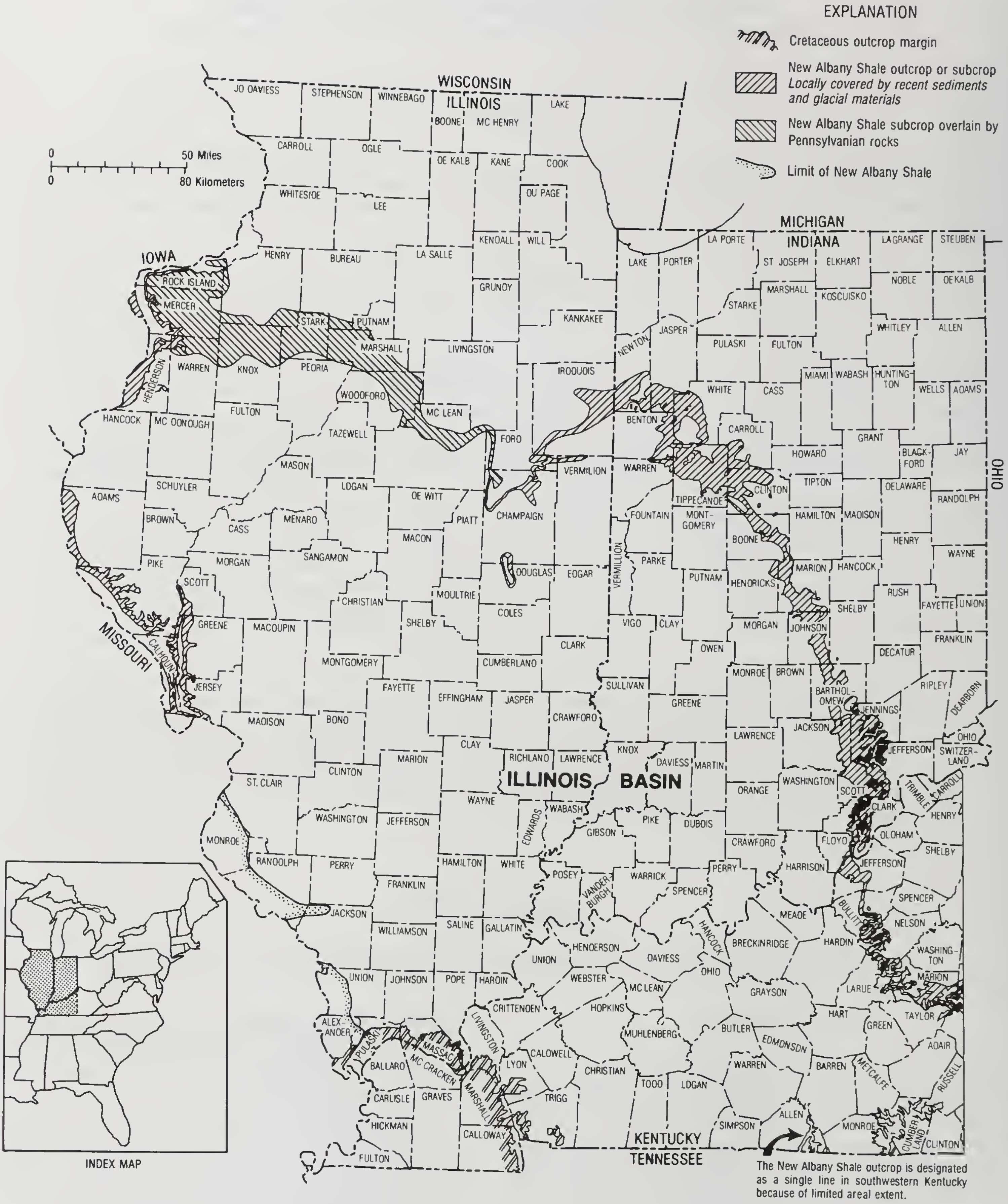


Figure 1. Map showing the location of the Illinois Basin, the outcrop of the New Albany Shale (Devonian and Mississippian), and county names in Illinois, Indiana, and Kentucky. The outcrop pattern defines the shape of the Illinois Basin. The New Albany Shale is present throughout the Illinois Basin.

relating to the gas potential; to cooperate with interested gas producers and operators to obtain new data, particularly in the deep part of the basin and in areas where there have been good gas shows or gas production from the shale; and to establish criteria that operators may use to identify areas in the basin having the greatest potential for gas production from the shale.

Background

Devonian shales in the Appalachian, Michigan, and Illinois Basins have been a source of natural gas in the eastern United States for approximately 170 years. To date, most of the Devonian shale gas has been produced from the Big Sandy Field in eastern Kentucky and western West Virginia.

The New Albany Shale (Devonian and Mississippian) is present throughout much of Illinois, southwestern Indiana, and western Kentucky (fig. 1). The presence of natural gas in the New Albany in western Kentucky has been known since the late 1800s. A gas field in Meade County, Kentucky, was developed in the late 1880s in the New Albany Shale at depths of 400 to 500 feet. An initial potential[1] (IP) of 4,500 thousand cubic feet of gas per day (MCFGPD) was reported for an individual well; the average IP from the best wells in the field was 500 MCFGPD (Jillson, 1931). Several other shallow New Albany gas fields were developed at depths of 300 to 500 feet in Meade County (Schwalb and others, 1971).

Gas has been produced from the shale at a depth of 1,425 feet in the Shrewsbury Field in Grayson County, Kentucky (Schwalb and others, 1971). During the 1970s several New Albany gas wells were placed on production in Trigg County and northern Christian County. Subsequently, additional testing of the shale has been conducted in Crittenden, Hopkins, Webster, and Union Counties in Kentucky.

The first drilling targeted specifically for gas from the New Albany Shale in Indiana occurred in 1885. Between 1885 and 1925, seven shallow gas fields were developed in the New Albany Shale in Harrison County, Indiana. Sorgenfrei (1952) estimated that 5 billion cubic feet (BCF) of gas were produced from Harrison County gas fields by Louisville Gas and Electric and Indiana Utility Corporation. Two older gas fields are present in Daviess County, Indiana, and one in Martin County, Indiana. Shows of gas have also been reported from the shale throughout southwestern Indiana (Bassett and Hasenmueller, 1981; Smidchens and Boberg, in review). Since 1980 nine additional New Albany Shale gas fields have been discovered in southwestern Indiana.

Although no gas production was reported from the New Albany Shale in Illinois until 1989, numerous gas shows had been reported from the shale. In 1989, the Russellville Field was discovered in Lawrence County, Illinois, by the Hux Oil Corporation. The discovery well was gauged at 60 MCFGPD following the stimulation of the New Albany at a depth of 2,750 to 2,788 feet. Two step-out wells had IP values of 199 and 100 MCFGPD from 2,724 to 2,766 and 2,698 to 2,738 feet, respectively.

Previous Studies

Early studies of the gas production from the New Albany Shale in the Illinois Basin include the 1890 report, "The Natural Gas Field of Indiana," by Phinney, which contains a discussion of gas production from the black shales in Harrison County, Indiana, and the 1931 report on natural gas in western Kentucky by Jillson. A detailed study that presents gas production data from Harrison and Martin Counties, Indiana, was made by Sorgenfrei in 1952.

Later studies resulting from the Eastern Gas Shales Project, sponsored by the U.S. Department of Energy (DOE), are contained in the following final reports: (1) Bergstrom and others (1980), who described geologic and geochemical studies relating to the New Albany Shale in Illinois, (2) Hasenmueller and Woodard (1981), who summarized the nature of the shale and previous gas production in Indiana, and (3) Schwalb and Norris (1980f), who characterized the geology and gas production from the shale in Kentucky. A brief report that summarized the results of these final reports from the three states was compiled by Lineback in 1980. Cluff and Dickerson (1982) discussed the gas potential of the shale in southeastern Illinois.

Studies relating to the stratigraphy of the shale include: Campbell (1946), Lineback (1968, 1970), Reinbold (1978), Reinbold and others (1980), Cluff and others (1981), Hasenmueller and Bassett (1981), Ettensohn and others (1989), Devera and Hasenmueller (1991), and Hasenmueller (1993).

The depositional environment of the shale has been described by Rich (1948), Lineback (1968, 1970), Pickering (1979), Cluff (1980), Cluff and others (1981), Ettensohn and Barron (1981), Beier and Hayes (1989), Ettensohn and others (1989), and Devera and Hasenmueller (1991).

Information related to the inorganic geochemistry of the New Albany Shale has been presented by Stevenson and Dickerson (1969), Frost (1980), Leininger (1981), Robl and others (1984), Shaffer and others (1983, 1984), Chou and Dickerson (1985), Frost and others (1985), Hasenmueller and others (1983b), and Hasenmueller and Leininger (1987). The types of phosphates present in the shale (Shaffer and others, 1988) and the effects of weathering (Shaffer and Leininger, 1986; Shaffer and Branam, 1991) and in situ gasification (Branam and others, 1991) on the shale have also been studied.

The mineralogy of the New Albany has been reported by Chen and Shaffer (1978), Shaffer and Chen (1981), Ripley and Shaffer (1989a), and Shaffer and Ripley (1992). Details of texture, especially as related to the metal enrichment first noted by Lechler and others (1980), have been evaluated by Ripley and Shaffer (1989b) and Ripley and others (1990).

---

[1] Results of initial production tests are reported as "initial production" to the Illinois State Geological Survey and Indiana Geological Survey and as "initial open flow" to the Kentucky Geological Survey. In this report, the initial production tests are reported as "initial potential" (IP).

Studies of isotopes of sulfur and carbon by Shaffer and others (1982), Hailer and others (1982), Beier and Hayes (1989), and Ripley and others (1990) have helped to elucidate depositional conditions and especially to highlight the anomalous nature of the Henryville Bed of the Clegg Creek Member, which has very low (more negative) sulfur isotope values, greater metal enrichment, and higher organic carbon to total sulfur ratios than other units in the shale.

Petroleum source rock studies that include the New Albany Shale have been published by Barrows and others (1979, 1980), Barrows and Cluff (1984), Chou and others (1991), Bethke and others (1991a-b), Cluff and Byrnes (1991), and Hatch and others (1991).

Many other studies of the New Albany Shale were completed as part of the Eastern Gas Shales Project. Papers on the shale are found in the three Morgantown Energy Technology Center Proceedings volumes for the Eastern Gas Shales Symposiums; other reports and maps are included in the Morgantown Energy Technology Center publication and map series. Additional information is available in the semi-annual reports for the unconventional gas recovery program. Many subsequent reports about the New Albany Shale are in the Proceedings of the Eastern Oil Shale Symposium, which has been published by the University of Kentucky, the Kentucky Center for Applied Energy Research, and the Institute for Mining and Minerals Research. The Gas Research Institute repositories contain numerous publications relating to the energy potential of organic-rich shales.[2] A selected bibliography, which includes additional Devonian shale references not cited in the text, is included at the end of this report (appendix A).

---

[2] GRI Natural Gas Supply Information Centers:

1) The University of Alabama
205 Tom Bevill Building
Tuscaloosa, AL 35487-0211
205/348-2839
FAX: 205/348-9268

2) Colorado School of Mines
Arthur Lakes Library
Golden, CO 80401-1887
303/273-3707
FAX: 303/273-3199

3) Marietta College
Dawes Memorial Library
Marietta, OH 45750-4027
614/376-4742
FAX: 614/376-4843

4) University of Houston
Dobrin Memorial Library (AGL)
Houston, TX 77204-4231
713/743-9158
FAX: 713/743-9164

DATA AND METHODS

By Wayne T. Frankie, Donald K. Lumm, Wesley S. Boberg, John B. Comer, and Terence Hamilton-Smith

Introduction

Comprehensive basinwide structural features, core location, stratigraphic, gas production, mineralogic, and source rock data for the New Albany Shale were compiled as part of this project. These data were derived from petroleum well records, published reports, and computerized and hard copy data files at the Illinois, Indiana, Kentucky, and U.S. Geological Surveys. The data for the study were compiled from 1990 to 1992.

Structural Features Map

The structural features map of the Illinois Basin (pl. 1) was created by digitizing structural features from individual state geological maps. Map sources included: (1) "Structural Features in Illinois-A Compendium" (Treworgy, 1981), (2) "Structural Features in Illinois" (Nelson, in press), (3) "Bedrock Geologic Map of Indiana" (Gray and others, 1987), and (4) geologic quadrangle maps for central and western Kentucky compiled by various authors. The unnamed faults in Butler and Edmonson Counties in western Kentucky were originally mapped by Noger (1982).

The structural features map shows the major structures in the Illinois Basin. These features have not necessarily been mapped on the top of the New Albany Shale. The faults in southern Illinois and westernmost Kentucky extend beneath the younger Cretaceous strata.

Core Location Data

Information on the location, depth, and recovered intervals was compiled for 201 cores that included total or partial sections of the New Albany Shale (appendix B). The core location map (pl. 2) shows the location of each well with core from the New Albany. The cores are stored either at one of the three state surveys or at the Kentucky Center for Applied Energy Research in Lexington, Kentucky.

Elevation and Thickness Data

The stratigraphic database compiled for the project contains information for more than 5,000 wells drilled into or through the New Albany Shale in the Illinois Basin. These data were used to create the elevation and thickness maps of the New Albany Shale (pls. 3 and 4). The contour interval on the elevation map is 250 feet; the contour interval on the thickness map is 20 feet.

The elevation map was compiled by plotting the elevation of the top of the New Albany Shale relative to sea level. The base of the formation was not contoured because the Blocher (Shale) Member, which is the basal member of the New Albany, grades laterally into Middle Devonian carbonate rocks (North, 1969; Reinbold, 1978; Cluff and others, 1981). In this study, correlations based on geophysical logs confirmed the gradational lithologic changes across the boundary between the Blocher and the underlying carbonate rocks in southeastern Illinois and southwestern Kentucky. This gradational characteristic of the Blocher prevents consistent placement of the base of the New Albany Shale. Thus, in the deeper part of the basin the top of the formation is a more reliable pick on geophysical logs than the base.

In the previous studies, elevation contour maps (scale 1:500,000) were compiled for the elevation of the base of the New Albany Shale in Illinois (Cluff and others, 1981) and Indiana (Bassett and Hasenmueller, 1979a). Maps were compiled for the elevation of the top of the shale in Kentucky at a scale of 1:250,000 (Schwalb and Potter, 1978) and in Indiana at a scale of 1:500,000 (Bassett and Hasenmueller, 1979b).

For this report, the map showing the elevation of the base of the New Albany Shale compiled by Cluff and others (1981), and in places the map of the elevation of the base of the Beech Creek (Barlow) Limestone (Mississippian) compiled by Bristol (1968), were used as guides in contouring the elevation of the top of the New Albany in Illinois. Elevation contours south of the Cottage Grove Fault System are more generalized than those to the north because of the lack of data.

The map of the elevation of the top of the New Albany Shale (pl. 3) and the map of the thickness of the New Albany (pl. 4) were initially contoured using ZYCOR, Inc. mapping software at the Illinois State Geological Survey and later hand modified by the staff at each survey. The final thickness and elevation contours were hand digitized at the Indiana Survey and computer plotted onto a 1:1,000,000 scale base map.

Cross Sections

Six cross sections detailing the lateral and vertical variability of the shale across the basin were constructed using geophysical logs (pl. 5). Key stratigraphic rock units (members) within the New Albany, as well as the overlying and underlying rock units, are designated on the cross sections.

Although most marker beds are widely traceable on the logs, some are difficult to correlate from one locality to another because of the poor quality of some of the logs and because of subtle changes in lithology, such as transitional zones between overlying and underlying stratigraphic units. Boundaries between stratigraphic units are defined principally by changes on gamma-ray, electrical resistivity, and bulk density logs. Although gamma-ray and density logs best enable the lithology of shale units to be identified, resistivity logs have historically been the most common type of geophysical log available for study in the Illinois Basin.

Cluff and others (1981) noted that major vertical lithologic changes within the New Albany Shale interval are generally indicated by abrupt changes in at least one geophysical property at very nearly the same log depth. The boundaries between members of the New Albany can, therefore, be defined by abrupt changes in log properties that represent significant lithologic changes (fig. 2). This is supported by comparison between logs and cores or well sample sets (cuttings) from the same well. More detailed descriptions of the geophysical characteristics of the individual members of the formation are found in Cluff and others (1981) and Hasenmueller and Bassett (1981).

Gas Production Data

Although gas has been produced from the New Albany Shale in the Illinois Basin for more than a century, available gas production data are sparse. Production data for the older wells were either never recorded or have not been preserved. Moreover, information about recent production is difficult to obtain. In Indiana and Kentucky, gas production data for individual wells, fields, or producing horizons are not generally available to the public. In Kentucky, gas production data are reported on a lease basis for tax and revenue purposes, but are held confidential.

The only measure of gas production from the New Albany Shale that is generally available throughout the Illinois Basin consists of IP measurements made during the initial completion of individual wells (pl. 6). These measurements are generally, but not always, taken soon after stimulation, at atmospheric back pressure, and without any recorded choke. IP data have been gleaned from published reports (Jillson, 1919, 1922, 1931; Sorgenfrei, 1952; Schwalb and Norris, 1980f), or from completion reports submitted to the state geological surveys by oil and gas operators. These measurements are generally much greater than actual production figures. An example from the Meade County gas field in Kentucky in 1890 suggests that production was 20 percent of IP (Jillson, 1922).

Mineralogical and Geochemical Data

Mineralogical and geochemical data referenced in this study of the New Albany Shale are primarily from reports generated during the Eastern Gas Shales Project by the Illinois and Indiana Geological Surveys (Frost, 1980; Harvey and others, 1980; Leininger, 1981; Shaffer and Chen, 1981; Frost and others, 1985). Unpublished data from chemical analyses of the New Albany, on file in the Geochemistry Section at the Indiana Geological Survey, were incorporated into the discussion of the sulfur and carbon contents of the shale.

Source Rock Data

Vitrinite reflectance data for the New Albany Shale were compiled from both published and unpublished data and reports generated by the Illinois State Geological Survey in the late 1970s and early 1980s. In these earlier studies, the mean random reflectance in oil ($\overline{R}_o$), which is the arithmetic mean of approximately 25 to 50 randomly oriented vitrinite and related grains in kerogen concentrates from each sample, was determined by reflected light microscopy. The kerogen concentrates were hydrofluoric and hydrochloric acid-insoluble residues that had been mounted in epoxy and polished for the microscopic analyses. In the present study, the quality of the data was evaluated by reviewing the raw data sheets that contained the original notes of the analysts. Details of the sample selection, sample preparation, and petrographic techniques are discussed more fully in Barrows and others (1979, 1980), and Barrows and Cluff (1984).

The reflectance data (appendix C) include average $\overline{R}_o$ values that summarize analyses of 520 samples from 223 different locations (273 samples from 129 locations in Illinois, 66 samples from 33 locations in Indiana, and 181 samples from 61 locations in Kentucky). In appendix C, each well is identified by a unique number and each sample is identified by the original laboratory analysis number, which is prefixed by the acronyms NAS (New Albany Shale), DWS (Deep Well Study), or a two-digit/two-letter combination ending with the state abbreviation (for example, 01IL, 13IL, 01IN). The NAS and DWS prefixes mostly identify samples from well cuttings, and the combination prefixes identify samples from cores. Also identified are the operator, well number, and farm name for each entry. For those wells with more than one sample in the New Albany Shale interval, an average $\overline{R}_o$ value was calculated. These average $\overline{R}_o$ values were used to create the mean random vitrinite reflectance map of the New Albany Shale in the Illinois Basin (pl. 7). Plate 7 was contoured using the $\overline{R}_o$ data shown on the map. In some areas where data were limited, $\overline{R}_o$ was inferred using the subsurface elevation of the New Albany Shale (pl. 3) based on the assumption that $\overline{R}_o$ is directly related to depth of burial.

Additional information about thermal maturity was derived from published Rock-Eval® T_{MAX} data (Chou and others, 1991) and from published and unpublished stable carbon isotope ratio ($\delta^{13}C$) data (Coleman, 1980; unpublished data compiled during the Eastern Gas Shales Project by the U.S. Geological Survey, George E. Claypool, Principal Investigator). Thirty-five core samples with both T_{MAX} and $\overline{R}_o$ values were used to verify the level of thermal maturity inferred from the $\overline{R}_o$ data. The carbon isotope data are reported as $\delta^{13}C$ where

$$\delta^{13}C = \frac{(^{13}C/^{12}C)_{Sample} - (^{13}C/^{12}C)_{Standard}}{(^{13}C/^{12}C)_{Standard}} \times 1000.$$

This formula represents the difference in the ratio of ^{13}C and ^{12}C relative to a standard, and has the units of parts per thousand (per mil or ‰). All $\delta^{13}C$ values in this report are based on the internationally accepted PDB standard, which is a belemnite from the Peedee Formation (Upper Cretaceous) of South Carolina. The carbon isotope analyses are for methane gas extracted from sealed canisters containing fresh New Albany Shale core samples. The data reviewed in this report are based on the analysis of 92 canned

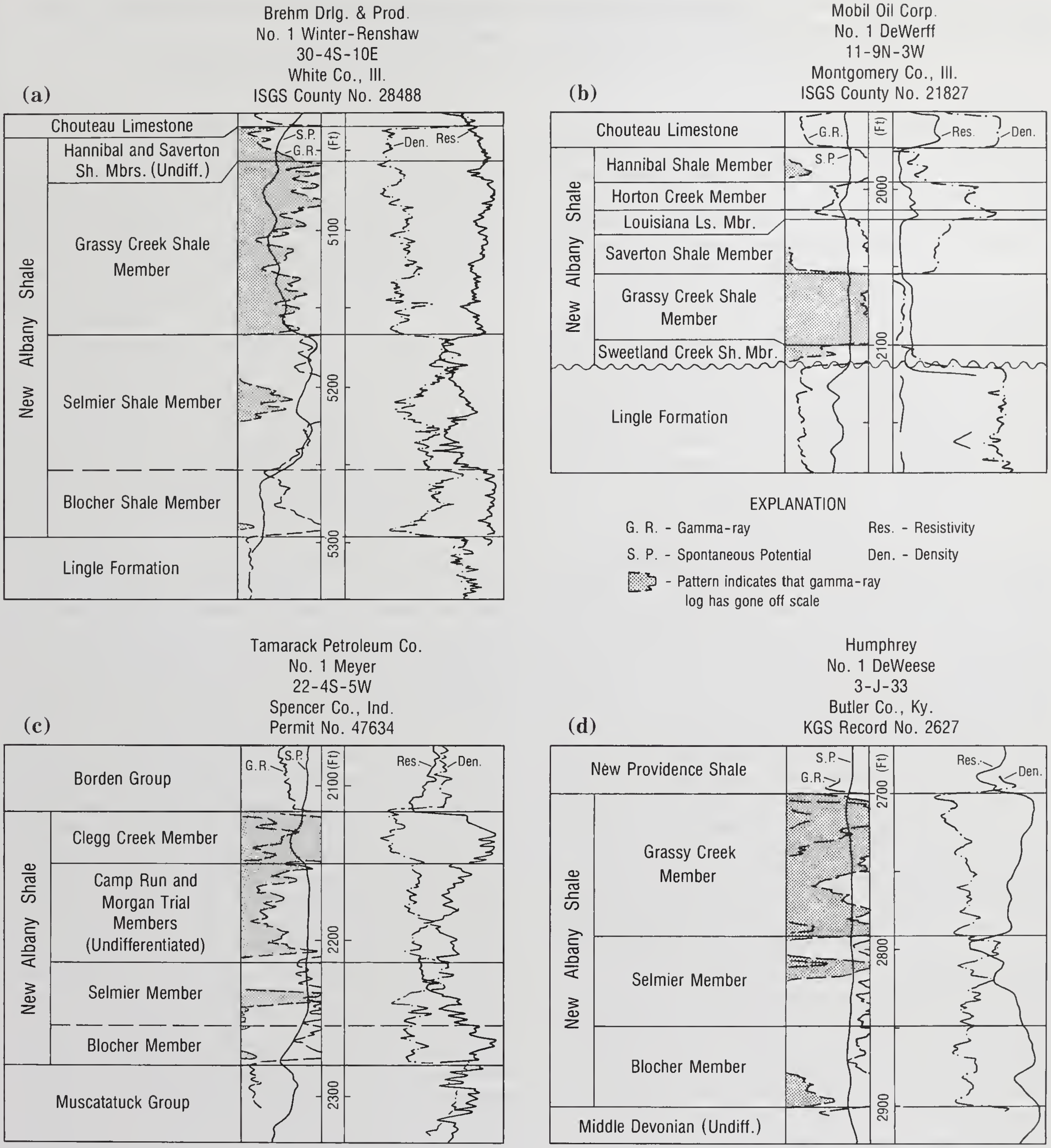


Figure 2. Subsurface reference sections for Illinois, Indiana, and Kentucky: a) Brehm Drilling and Production No. 1 Winter-Renshaw, Sec. 30, T. 4 S., R. 10 E., White County, Illinois (see also plate 5, cross sections A-A' and E-E', well no. 13); b) Mobil Oil Corportation No. 1 DeWerff, Sec. 11, T. 9 N., R. 3 W., Montgomery County, Illinois (see also plate 5, cross section A-A', well no. 8); c) Tamarack Petroleum Co. No. 1 Meyer, Sec. 22, T. 4 S., R. 5 W., Spencer County, Indiana (see also plate 5, cross sections B-B' and E-E', well no. 39); and d) Humphrey No. 1 DeWeese, 3-J-33, Butler County, Kentucky (see also plate 5, cross sections B-B' and F-F ', well no. 47).

core samples. The $\delta^{13}C$ data provided information about the relative thermal maturity of the gas and were used to determine whether methane in the New Albany Shale is of thermal or bacterial origin.

ILLINOIS BASIN GEOLOGIC SETTING

By Donald K. Lumm, Wayne T. Frankie, Nancy R. Hasenmueller, and Terence Hamilton-Smith

Geologic Overview

The Illinois Basin (also known as the Eastern Interior Basin) covers approximately 60,000 square miles in parts of Illinois, southwestern Indiana, and western Kentucky (fig. 1). The basin contains about 100,000 cubic miles of Cambrian through Permian sedimentary rocks. Some Cretaceous and Tertiary strata and extensive unconsolidated Quaternary deposits cover most of the Paleozoic bedrock.

The Illinois Basin is bounded by the Cincinnati Arch on the east, the Pascola Arch on the south, the Ozark Dome on the west, the Mississippi River Arch on the northwest, and the Kankakee Arch on the northeast (fig. 3, pl. 1). Older Paleozoic bedrock units are exposed along the axes of some of these surrounding positive structures. The northeastern part of the New Madrid Rift Complex underlies the southern part of the Illinois Basin. The rift complex consists of the Reelfoot Rift and the contiguous Rough Creek Graben (fig. 3).

The Illinois Basin is classified alternately as an intracratonic basin (Bois and others, 1982), interior cratonic basin (Klemme, 1980; Klein, 1987), or interior sag basin (Kingston and others, 1983). The Illinois Basin is a polyhistory basin that began as a rift complex that gradually evolved into a cratonic embayment. Subsequent modification of the cratonic embayment by major tectonic events led to structural closure and the formation of its present geometry (Buschbach and Kolata, 1991).

The New Madrid Rift Complex is considered to be a failed rift or aulacogen that was formed during the breakup of a supercontinent during Early to Middle Cambrian time (Braile and others, 1984; Buschbach and Kolata, 1991). Lithospheric extension and associated tension block (normal) faulting within the incipient Reelfoot Rift and Rough Creek Graben apparently were accompanied by rapid subsidence and sedimentation. Major rifting apparently ceased by Late Cambrian time (Buschbach and Kolata, 1991). The Rome Trough, a rift in eastern Kentucky, trends east-west and is in line with the Rough Creek Graben. The connection of the Rough Creek Graben to the Rome Trough has been suggested by Thomas (1991). The incipient Reelfoot Rift connected the proto-Illinois Basin to the pericratonic Arkoma and Black Warrior Basins to the south. Regional downwarping of both the rift complex and the surrounding cratonic areas continued throughout most of the Paleozoic (Sloss, 1979). This subsidence resulted in the formation of a sedimentary basin above the rift complex that extended beyond the original boundaries of the rift.

Uplands formed by the Taconic and Acadian Orogenies supplied clastic sediments to the Illinois Basin. The greatest thickness of the New Albany Shale was deposited in the deeper part of the basin over the rift complex.

Major deformation in the Illinois Basin occurred concurrently with the late Paleozoic Ouachita and Alleghenian Orogenies. This deformation not only reactivated some of the rift structures, but produced new structural elements elsewhere in the basin. During post-Pennsylvanian to Late Cretaceous time, the Pascola Arch was uplifted, structurally closing the southern end of the embayment and establishing the present oval-shaped geometry of the Illinois Basin (Buschbach and Kolata, 1991).

Deep drilling and seismic reflection profiles indicate that the present thickness of sedimentary rocks ranges from about 3,000 feet at the margins of the basin to as much as 23,000 feet in the Rough Creek Graben in western Kentucky (Buschbach and Kolata, 1991). The sedimentary fill overlies Precambrian granite and rhyolite, dated between 1,420 and 1,500 Ma (Bickford and others, 1986). The sedimentary rocks consist primarily of marine carbonates and, to a lesser extent, sandstone, shale, siltstone, and coal.

Major Structural Features

The Illinois Basin contains many significant structural elements representing a variety of structural styles. The largest structures are those that bound or are associated with the Reelfoot Rift and the Rough Creek Graben (fig. 3). Seismic-reflection profiles indicate that the Reelfoot Rift is a northeast-trending graben that is bounded by sets of listric normal faults that penetrate basement (Nelson, 1991). A pronounced upwarping of Paleozoic strata is interpreted along a fault near the centerline of the rift (Howe and Thompson, 1984). Faults in the Reelfoot Rift have been reactivated several times under different stress regimes. Some are active today and are responsible for recurrent activity within the New Madrid Seismic Zone (Nelson, 1991).

The Rough Creek Graben is an eastern "dogleg" extension of the Reelfoot Rift (fig. 3). The graben is asymmetrical, with greater displacements along its northern margin. The east-west-trending Eagle Valley and Moorman Synclines (pl. 1) represent broad, gentle folds within the Rough Creek Graben.

The northern margin of the Rough Creek Graben is expressed at the surface by the Rough Creek Fault System and Shawneetown Fault Zone (pl. 1). The master fault is high-angle reverse near the surface. Seismic-reflection profiles indicate that the master fault is listric normal in the deep subsurface (Bertagne and Leising, 1991). The Shawneetown Fault Zone makes a sharp bend to the south-southwest in Saline County, Illinois, and joins the Lusk Creek Fault Zone (pl. 1) several miles farther south. The Lusk Creek Fault Zone projects to the southwest and beneath undisturbed Late Cretaceous strata of the Mississippi Embayment. The trend of the Rough Creek Fault System changes abruptly to the southeast in Grayson County in western Kentucky.

The southern margin of the Rough Creek Graben is less well defined, but it generally corresponds to a series of unnamed, east-

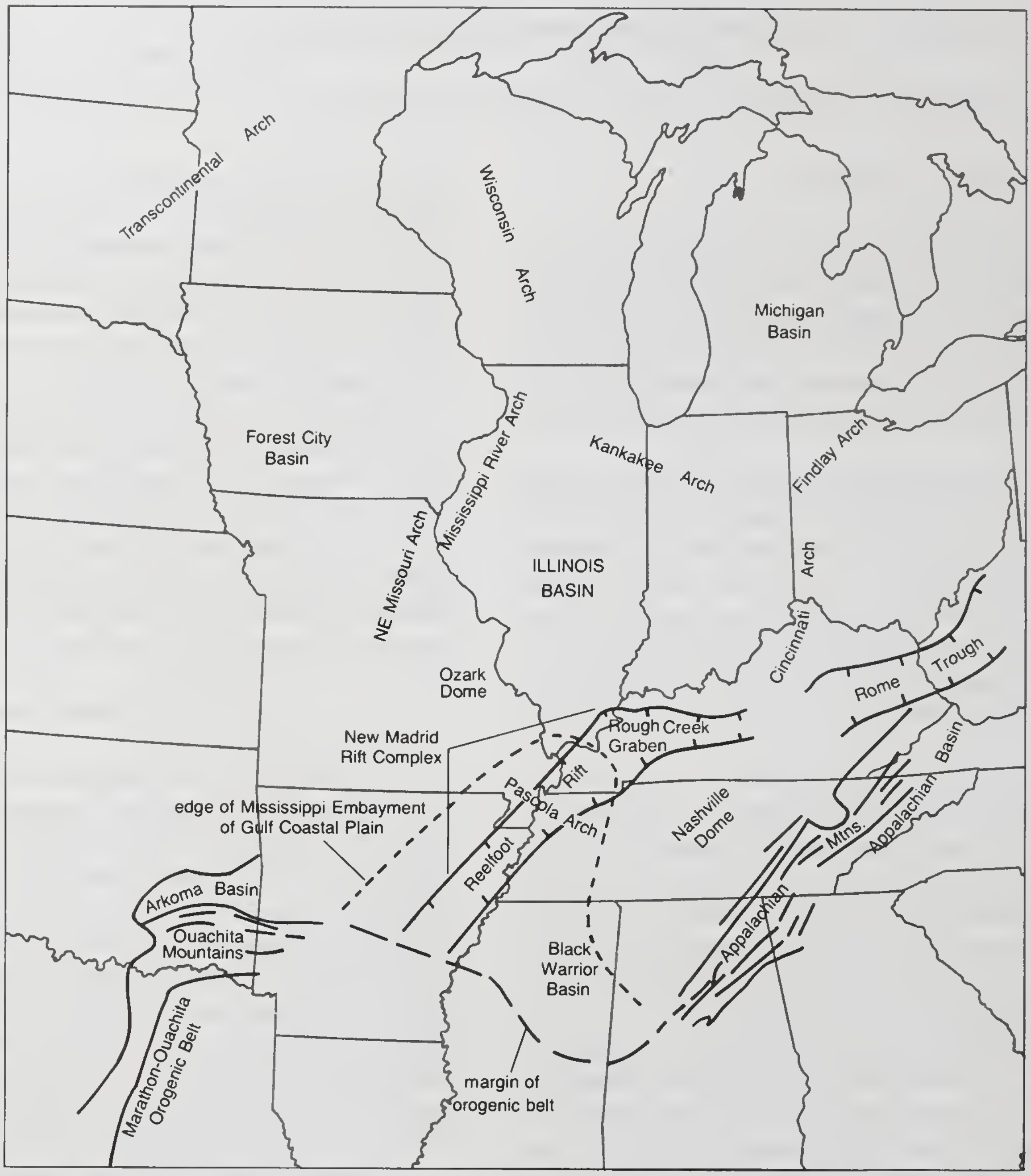


Figure 3. Map showing major tectonic features in the eastern Midcontinent region of the United States. Modified from Shumaker (1986) and Buschbach and Kolata (1991).

west-trending faults situated about 5 to 10 miles south of the Pennyrile Fault System (pl. 1). These poorly exposed faults are predominantly north-dipping and high-angle normal. The faults trend to the southwest in Trigg County, Kentucky, and project in the subsurface to the Mississippi Embayment. To the east, unnamed faults mapped in the subsurface in Butler and Edmonson Counties appear to merge with the Pennyrile Fault System in northeastern Warren County; the merged systems may intersect the southeastern extension of the Rough Creek Fault System in southeastern Grayson and northwestern Hart Counties (Williams and others, 1982).

The Fluorspar Area Fault Complex is located southeast of the Lusk Creek Fault Zone and south of the Rough Creek Fault System and Shawneetown Fault Zone in southernmost Illinois and adjacent Kentucky (pl. 1). It is composed of the broad, northwest-striking Tolu Arch, which has been broken by northeast-oriented fault blocks (Buschbach and Kolata, 1991). The faults are herein interpreted to be predominantly high-angle normal, but they have also been interpreted as high-angle reverse and strike-slip (Baxter and others, 1967; Trace, 1974). Hicks Dome, a nearly circular cryptoexplosion structure 10 miles in diameter with 4,000 feet of uplift, is in Hardin County, Illinois (pl. 1) (Baxter and Desborough, 1965; Baxter and others, 1967; Hook, 1974; Trace, 1974).

The Wabash Valley Fault System consists of a series of high-angle normal faults that strike north-northeast along the Wabash River valley in southeastern Illinois and southwestern Indiana, and extend into western Kentucky (pl. 1) (Bristol and Treworgy, 1979). Some of the faults connect with, but do not cross, the Rough

Creek Fault System and Shawneetown Fault Zone to the south (Nelson and Lumm, 1984, 1987). The faults outline grabens, and seismic profiles indicate that there is less stratigraphic offset in the deep subsurface than at the surface (Braile and others, 1984; Nelson and Lumm, 1984, 1987).

The Cottage Grove Fault System is a complex association of structures within a 10-mile-wide zone that trends westward across southern Illinois from Gallatin to Jackson Counties (pl. 1) (Nelson and Krausse, 1981; Nelson and Lumm, 1984, 1987). The master fault is a high-angle right-lateral wrench fault. Other faults are normal, reverse, strike-slip, and oblique slip. Numerous subsidiary anticlines, synclines, and drag folds are associated with the master and minor faults (Nelson and Krausse, 1981; Nelson and Lumm, 1985).

The Ste. Genevieve Fault Zone is situated on the western margin of the Illinois Basin along the northeastern flank of the Ozark Dome and trends southwestward from eastern Missouri to Union County in southwestern Illinois (pl. 1). The main part of the fault zone is characterized by high-angle reverse faults that are flanked by smaller high-angle normal and reverse faults (Nelson and Lumm, 1985).

The Fairfield Basin is the central deepest part of the Illinois Basin north of the Reelfoot Rift-Rough Creek Graben area. The Fairfield Basin is bounded by the Rough Creek Fault System, Shawneetown Fault Zone, and Cottage Grove Fault System on the south, the Du Quoin Monocline to the west, and the La Salle Anticlinorium to the east and northeast (pl. 1). The center of this sub-basin is near Fairfield, Wayne County, Illinois, where it contains nearly 14,000 feet of sedimentary rocks (Buschbach and Kolata, 1991).

The La Salle Anticlinorium is a major subsurface structure that strikes south-southeast from Lee County in north-central Illinois to Lawrence County in southeastern Illinois (pl. 1). For much of its 200-mile length, the western side of the La Salle belt is bounded by a pronounced monoclinal fold that rises above the basin floor by as much as 2,000 feet. North-south-trending anticlines and synclines are situated east of the monocline (Buschbach and Kolata, 1991).

The Du Quoin Monocline trends north-south and forms the western margin of the Fairfield Basin (pl. 1). The steep side of the monocline dips to the east, and its western flank forms the relatively shallow Sparta Shelf (pl. 1) (Buschbach and Kolata, 1991).

The Waterloo-Dupo Anticline trends south-southeast in St. Clair and Monroe Counties, Illinois (pl. 1). Its steepest flank is to the west. The Cap au Grès Faulted Flexure strikes eastward in Jersey County, Illinois (pl. 1). It consists of a narrow zone of intense folding and faulting (Rubey, 1952; Buschbach and Kolata, 1991).

The Sangamon Arch is a broad, east-northeast-trending feature in west-central Illinois (pl. 1). The feature has no surface structural expression, but is inferred from Silurian through Upper Devonian-Kinderhookian strata that thin and pinch out across it (Whiting and Stevenson, 1965; Collinson and others, 1967). The arch was active during New Albany Shale deposition, which resulted in a thinning of the New Albany. This thinning, referred to as the "central thin" by Cluff and others (1981), is between the "southern depocenter" and the "western depocenter" of the New Albany Shale and is somewhat south of the crest of the Middle Devonian Sangamon Arch (Cluff and others, 1981).

The Media Anticline is a small feature, but like the Sangamon Arch is presumed to have been active during deposition of the New Albany Shale (Nelson, in press). The anticline trends west-northwest and is located near Media, Henderson County, Illinois (Bell and Workman, 1928) (pl. 1). The New Albany Shale thins markedly across the structure, whereas there is little or no thinning of strata older than the New Albany. Minor movement of the structure occurred after deposition of the Burlington Limestone (Valmeyeran) (Nelson, in press).

The Mt. Carmel Fault trends north-northwest, for approximately 50 miles from northern Washington County to northern Monroe County in south-central Indiana (pl. 1). This fault is a normal fault and strata are downthrown to the west with a maximum vertical displacement of 200 feet (Sullivan and others, 1982). Seismic data indicate that the Mt. Carmel Fault reaches basement (Sullivan and others, 1982). Rudman and others (1965) noted a definite change in the gradient of the basement surface in central Indiana at the location of the fault and suggested that the change in gradient marks the position of a structural hinge separating the stable Indiana-Ohio Platform from the Illinois Basin to the west. Melhorn and Smith (1959) related the Mt. Carmel Fault genetically to the La Salle Anticlinorium by the general orientation combined with other structural aspects. They considered the fault and associated folding to be post-Valmeyeran.

West of the Mt. Carmel Fault is a belt of elongate domes and anticlines named the Leesville Anticline (pl. 1) (Melhorn and Smith, 1959). The domes and anticlines have axes parallel to the Mt. Carmel Fault and steeper flanks facing the fault; closure on the folds is 30 to 60 feet on Devonian and Mississippian strata (Melhorn and Smith, 1959).

Numerous pinnacle reefs and pinnacle-reef complexes of Silurian age are present in the subsurface of southwestern Indiana and eastern Illinois and have generally been interpreted as nontectonic structures. In southwestern Indiana, numerous reefs are present along the Terre Haute Bank in Clay, Daviess, Dubois, Greene, Owen, Spencer, Sullivan, and Vigo Counties (Ault and others, 1992). These Silurian reefs can be as much as 800 feet thick and are typically lithologically distinct compared with the horizontally bedded strata that enclose them (Droste and Shaver, 1980). Studies of the buried Silurian reefs have shown so-called drape structure in the inter-reef and post-reef strata enclosing the reefs (Droste and Shaver, 1980). Closure on such structure extends upward and affects Pennsylvanian strata (Becker and Keller, 1976). The closure on the top of the carbonate rocks of the Muscatatuck Group (Middle Devonian) that underlie the New Albany Shale ranges from 80 feet for the reef complexes at

Worthington and Plummer in Greene County, Indiana, to 200 feet for a pinnacle reef near Linton in Greene County (Droste and Shaver, 1980).

Three structures, the Kentland, Des Plaines, and Glasford disturbances, are classified as impact structures and were probably caused by impact of extraterrestrial objects. A more detailed discussion of these structures can be found in Nelson (1991).

Elevation of the Top of the New Albany Shale

Elevation of the top of the New Albany Shale (pl. 3) ranges from more than 750 feet above sea level in northwestern Indiana near the outcrop belt to more than 4,500 feet below sea level in southeastern Illinois. Locally, the elevation of the top of the formation is affected by the major fault and anticlinal-synclinal systems and also by buried Silurian reefs.

The regional dip of the New Albany Shale is 20 to 30 feet per mile near the margin of the basin and increases to 50 to 60 feet per mile toward the center of the basin. The dip varies locally because of faults, anticlines, synclines, and small structural domes.

The -4,500-foot elevation contour outlines the deepest area and corresponds to the general outline of the Fairfield Basin (pl. 1), the present structural center of the Illinois Basin. During the deposition of the New Albany Shale, the structural center of the basin was located farther south and corresponded to the area of thick New Albany Shale referred to as the southern depocenter by Lineback (1980, fig. 3).

Vertical displacements of more than 200 feet of the New Albany Shale are present within the Wabash Valley Fault System, and vertical displacements of more than 500 feet are present along the eastern end of the Cottage Grove Fault System in southeastern Illinois. The majority of the offset is interpreted as post-Pennsylvanian and therefore did not influence New Albany deposition.

STRATIGRAPHY

By Nancy R. Hasenmueller, Wesley S. Boberg, Donald K. Lumm, Wayne T. Frankie, Terence Hamilton-Smith, and John B. Comer

Introduction

The name New Albany Black Slate was originally proposed by Borden (1874) for brownish-black shale exposed along the Ohio River at New Albany, Floyd County, Indiana. This unit is currently designated the New Albany Shale. The New Albany consists of brownish-black, organic-rich and greenish-gray, organic-poor shale and is present in the subsurface throughout much of the Illinois Basin. The formation is a time-transgressive unit and consists of rocks of the Middle Devonian to Kinderhookian (Early Mississippian) (Cluff and others, 1981); however, most of the New Albany Shale is Late Devonian.

In the Kentucky portion of the Illinois Basin, geologists working during the second half of the nineteenth century applied the name New Albany Shale to outcrops along the western flank of the Jessamine Dome south and southeast of Jefferson County (de Witt, 1981). Significant earlier biostratigraphic studies include Savage (1930), who produced a detailed report of the distribution and character of the New Albany Shale in Kentucky, and Campbell (1946), who distinguished stratigraphic units within the New Albany Shale in Indiana and Kentucky in large part on the basis of faunal zones.

Use of the name New Albany was extended into Illinois by Workman and Gillette (1956). The interval was later designated the New Albany Shale Group in Illinois by Collinson and Atherton (1975), but has since been ranked as a formation in the southern part of the state by Nelson (in preparation) in order to be consistent with the rank currently used in Indiana and Kentucky. In this report, the New Albany Shale is ranked as a formation throughout the Illinois Basin.

Thirteen previously named units, herein recognized as members, makeup the New Albany Shale in this report (fig. 4). In ascending stratigraphic succession, these members are the Blocher, Sylamore, Selmier, Sweetland Creek, Grassy Creek, Morgan Trail, Camp Run, Clegg Creek, Saverton, Louisiana, Horton Creek, Hannibal, and Ellsworth. Five formally named beds, the Falling Run, Underwood, Henryville, Nutwood, and Jacobs Chapel, are also recognized (fig. 4). To make the ranking of stratigraphic units consistent basinwide, those units that were previously recognized as formations in Illinois (namely, the Blocher Shale, Sylamore Sandstone, Selmier Shale, Sweetland Creek Shale, Grassy Creek Shale, Saverton Shale, Louisiana Limestone, Horton Creek Formation, and Hannibal Shale) are here ranked as members of the New Albany Shale. The lithologic descriptors (for example, shale, sandstone, and limestone) are retained as part of the formal names of the members in Illinois (fig. 4).

In Kentucky, the New Albany Shale was differentiated into the Blocher Member, Sweetland Creek Member, and Grassy Creek Member by Schwalb and Norris (1980f). In this study, the use of the name Selmier Member has been extended into Kentucky to replace the name Sweetland Creek Member.

Thickness and Extent of the New Albany Shale

The New Albany Shale is present throughout much of the subsurface of the Illinois Basin; however, natural exposures are rare because of widespread Pleistocene and Holocene deposits that mantle the bedrock. The formation reaches a maximum thickness of more than 460 feet in Hardin County in southeastern Illinois and in adjacent Union and Crittenden Counties in western Kentucky (pl. 4). This area of thick New Albany is located south of the Shawneetown Fault Zone and Rough Creek Fault System (pl. 4). An area of thick shale extends eastward into west-central Kentucky along the Moorman Syncline.

The area of thick shale in southeastern Illinois and western Kentucky is referred to as the southern depocenter; laminated black shale is the predominant lithology within the depocenter (Lineback, 1980; Cluff and others, 1981). This depocenter overlies the junction between the Reelfoot Rift and the Rough Creek Graben (fig. 3) and apparently corresponds to the ancestral Illinois Basin during Middle and Late Devonian time.

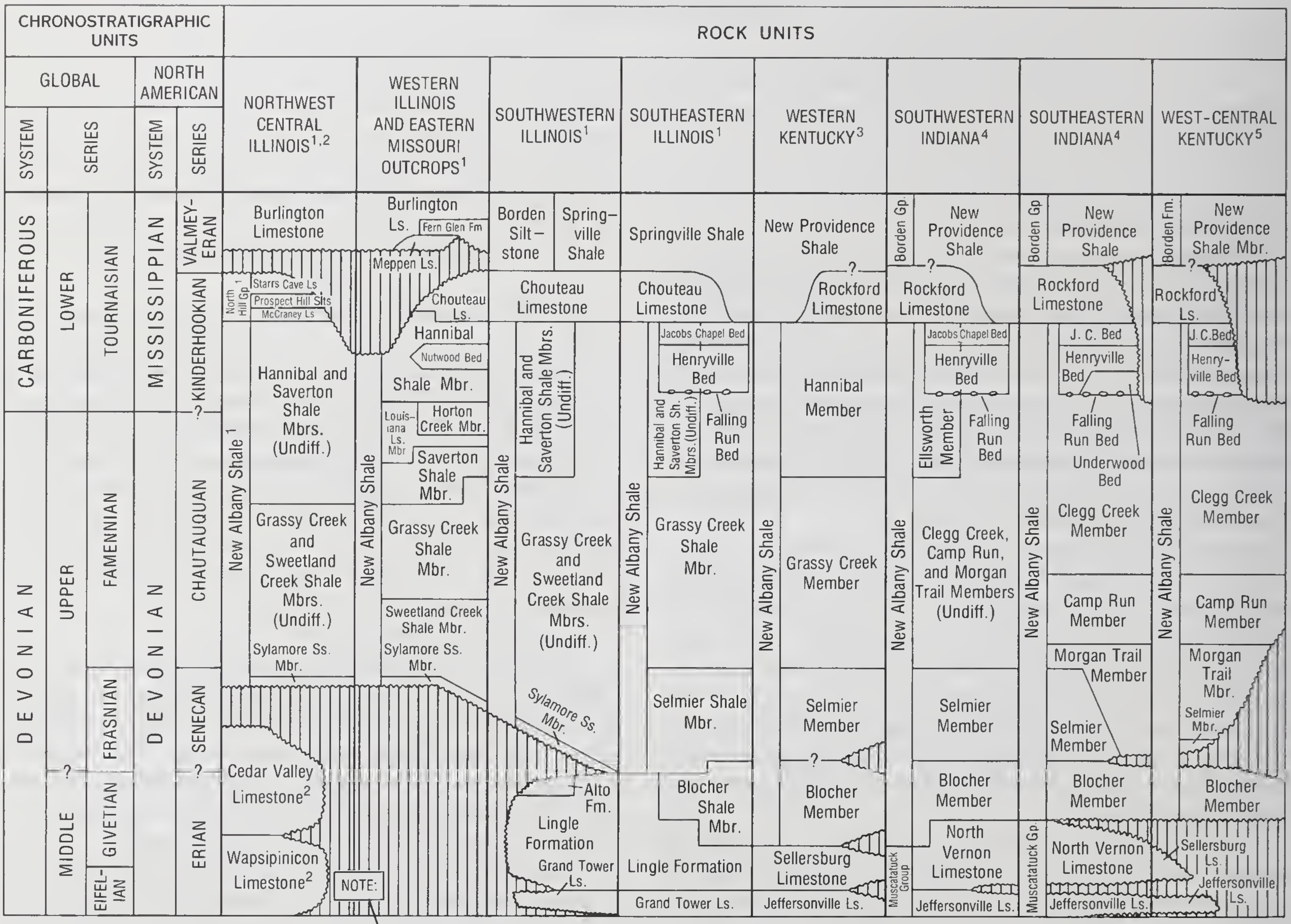
Another area of thick shale is located in southeastern Iowa and adjacent west-central Illinois. Workman and Gillette (1956) referred to this region as the Petersburg Basin. Predominant lithologies of the western depocenter are bioturbated olive-gray and greenish-gray shales of Late Devonian and Kinderhookian age (Lineback, 1980; Cluff and others, 1981). In Henderson and Hancock Counties, Illinois, the New Albany attains a maximum thickness of more than 300 feet.

The two depositional centers are separated by an area located in central Illinois referred to as the central thin by Lineback (1980). The central thin trends northeast-southwest and the New Albany Shale is generally less than 120 feet thick along its crest. Gray and brownish-black shales interfinger in this area.

A second area of thin New Albany, where the shale is less than 80 feet thick, trends north-south from Champaign and Vermilion Counties to Coles and Edgar Counties in east-central Illinois, and corresponds to the Brocton Dome. The New Albany is thin in this area because of uplift along the La Salle Anticlinorium (Cluff and others, 1981).

The formation thins rapidly westward from the southern depocenter across the Du Quoin Monocline, then thins gradually westward. Its erosional limit is along an eastern extension of the Ozark Dome (Workman and Gillette, 1956) referred to as the Sparta Shelf (Meents and Swann, 1965).

In western Illinois, the New Albany crops out along the west-



Sub-Sylamore unconformity extends into Ordovician rocks in northwest central Illinois and western Illinois

1 Modified from Cluff and others (1981)
2 From Shaver and others (1985)
3 Modified from Schwalb and Norris (1980f)
4 From Hasenmueller and Bassett (1981)
5 Modified from Conkin and Conkin (1972); Beard (1980); Sable and Dever (1990); and Ettensohn and others (1991)

Figure 4. Correlation of the New Albany Shale in the Illinois Basin. (Thicknesses not to scale.) Modified from Hasenmueller (1993).

central edge of the basin adjacent to the Mississippi River (fig. 1). The shale subcrops beneath thick Pleistocene glacial deposits along a trend extending southward from northeastern Illinois through northwestern Indiana into central Indiana. From central Indiana, the shale crops out in a belt that trends southward into the central part of northwestern Kentucky along the western flank of the Cincinnati Arch. The northern limit of the shale in Illinois is the subcrop beneath Pennsylvanian strata. The absence of the New Albany Shale in southwestern Illinois is partly a result of erosion and partly a result of nondeposition (Cluff and others, 1981) (fig. 1).

The upper part of the New Albany Shale in most of west-central Illinois has been truncated and is unconformably overlain by the Valmeyeran Meppen Limestone, Fern Glen Formation, and Burlington Limestone (Cluff and others, 1981) (fig. 4). The original thickness of the New Albany Shale in west-central Illinois may have been substantially greater than its present thickness.

Adjacent to the subcrop or outcrop area in southern Indiana the shale ranges in thickness from less than 100 feet to more than 140 feet (pl. 4). In general, the shale thickens in a southwesterly direction to more than 360 feet in Posey County, Indiana; however, the shale thins over the Terre Haute Bank and associated buried Silurian reef structures from Vigo and Sullivan Counties southward to Daviess County. Much of the localized thinning above the buried reefs appears to be due to post-Kinderhookian/pre-Valmeyeran erosion of the top of the Clegg Creek Member of the New Albany (Hasenmueller, 1989b). The New Albany Shale thickens to more than 160 feet in Benton County, Indiana, and adjacent counties to the north; this increase in thickness is largely the result of thickening of the Ellsworth Member.

Bounding Stratigraphic Units

In most of the Illinois Basin the New Albany Shale overlies Middle Devonian limestone (Shaver, 1985). The contact with the underlying limestone is generally conformable in southern and eastern Illinois. Farther to the north and west the basal unit, the Blocher Shale Member, grades laterally into the argillaceous limestone, dolostone, and shale of the Lingle and Alto Formations (North, 1969). Similarly, in western Kentucky the lower part of the Blocher grades into the argillaceous limestone and shale of the underlying Middle Devonian carbonate rocks (fig. 4, pl. 5).

In much of the northwestern part of the basin the New Albany overlies the Cedar Valley Limestone (Middle Devonian to lowermost Upper Devonian). The contact, where exposed, is erosional, indicating a minor unconformity, but fossil evidence suggests a relatively brief hiatus (Collinson and Atherton, 1975).

In west-central Illinois on the Sangamon Arch the New Albany unconformably overlies Silurian carbonate rocks and, in one small area, the Ordovician Maquoketa Group (Workman and Gillette, 1956). In southwestern Illinois on the flank of the Ozark Dome the New Albany unconformably overlies Ordovician, Silurian, and Lower Devonian strata (Workman and Gillette, 1956).

Throughout southeastern Indiana (fig. 4) the New Albany unconformably overlies the North Vernon Limestone (Middle Devonian) of the Muscatatuck Group. In much of western Kentucky the New Albany unconformably overlies Middle Devonian carbonate rocks. In some areas of south-central Kentucky the shale unconformably overlies Ordovician and Silurian strata.

The New Albany Shale is overlain by Mississippian (Kinderhookian to Valmeyeran) strata throughout most of the Illinois Basin. However, in northern Illinois the formation has been partly eroded and is overlain by Pennsylvanian strata. In a small area in extreme southern Illinois the shale is overlain by Upper Cretaceous strata (Collinson and Atherton, 1975) (pl. 1).

The New Albany is overlain by the Rockford Limestone (Kinderhookian to lower Valmeyeran) in much of Indiana (Rexroad and Scott, 1964); however, locally in Indiana where the Rockford is absent, the formation is unconformably overlain by the New Providence Shale of the Borden Group (Valmeyeran). In most of western Kentucky the New Albany Shale is overlain by the Rockford Limestone; where the Rockford is not present the New Albany is overlain by the New Providence Shale or the Fort Payne Formation. In extreme western Kentucky the Hannibal Member is the uppermost unit of the New Albany Shale (Lineback, 1980; Schwalb and Norris, 1980a, 1980c-d).

In most of southern and eastern Illinois the New Albany is overlain conformably by the Chouteau Limestone (Kinderhookian), which is laterally equivalent to the Rockford Limestone (fig. 4). In an area of east-central Illinois it is overlain by the Borden Siltstone, and in two areas in southeastern and extreme southern Illinois the New Albany Shale is overlain by the Springville Shale, a facies equivalent of the Borden Siltstone. Workman and Gillette (1956) suggested that post-Kinderhookian uplift and erosion in the north may have removed the Chouteau Limestone and part of the Kinderhookian strata assigned to the New Albany Shale. However, thickness trends indicate depositional thinning and possibly nondeposition over parts of an ancestral arch (Cluff and others, 1981).

In extreme western Illinois the Hannibal Shale Member is conformably overlain by the McCraney Limestone and laterally intergrades with it. In the areas of northwestern Illinois where the Chouteau and the North Hill Group are absent abundant conodont faunas in the Hannibal indicate that the upper part of the member is equivalent to the Chouteau Limestone (Atherton and others, 1975).

In most of the northwestern part of the basin the New Albany, as well as the Chouteau and its age equivalents, are truncated and unconformably overlain by Valmeyeran strata (Atherton and others, 1975) (fig. 4). Where present, the basal Valmeyeran formation is the Meppen Limestone. The Fern Glen Formation overlies the Meppen Limestone, but over most of the northwestern part of the basin the Burlington Limestone unconformably overlies the New Albany Shale (fig. 4).

Correlation of the New Albany Shale with Devonian Shales in the Appalachian and Michigan Basins

Correlation of the New Albany Shale with Devonian shales of the Appalachian and Michigan Basins is based in large part on the biostratigraphic marker *Foerstia* (*Protosalvinia*). *Foerstia* has been regarded as having affinities with marine fucoids of brown algae (Schopf and Schwietering, 1970); however, it has also been suggested that the tough thalloid form is more consistent with a terrestrial growth site (Gray and Boucot, 1977, 1979). *Foerstia* appears to be confined to a restricted time-stratigraphic zone within shales and siltstones of the Upper Devonian in the eastern United States.

In core samples of the New Albany from Indiana and western Kentucky the *Foerstia* Zone is present in the Clegg Creek and Grassy Creek Members of the New Albany Shale. The position of the *Foerstia* interval indicates that the Clegg Creek and Grassy Creek are equivalent to the Huron Member of the Ohio Shale of the Appalachian Basin (Kepferle, 1981; Hasenmueller and others, 1983a; Ettensohn and Geller, 1987) (fig. 5). Although *Foerstia* has not been recognized in Illinois, it has been reported as far west as Sullivan County, Indiana, and is likely to be present in southeastern Illinois (Hasenmueller, 1993). *Foerstia* is also found in the Antrim Shale in the Michigan Basin (Hasenmueller and others, 1983a; Matthews, 1983) (fig. 5).

Members and Beds of the New Albany Shale

The individual stratigraphic units within the New Albany Shale are identified in terms of dominant lithologies. Changes from one lithology to another (from one member to another) within the New Albany include both large- and small-scale interbedding, intertonguing, and gradations. Detailed correlations based on

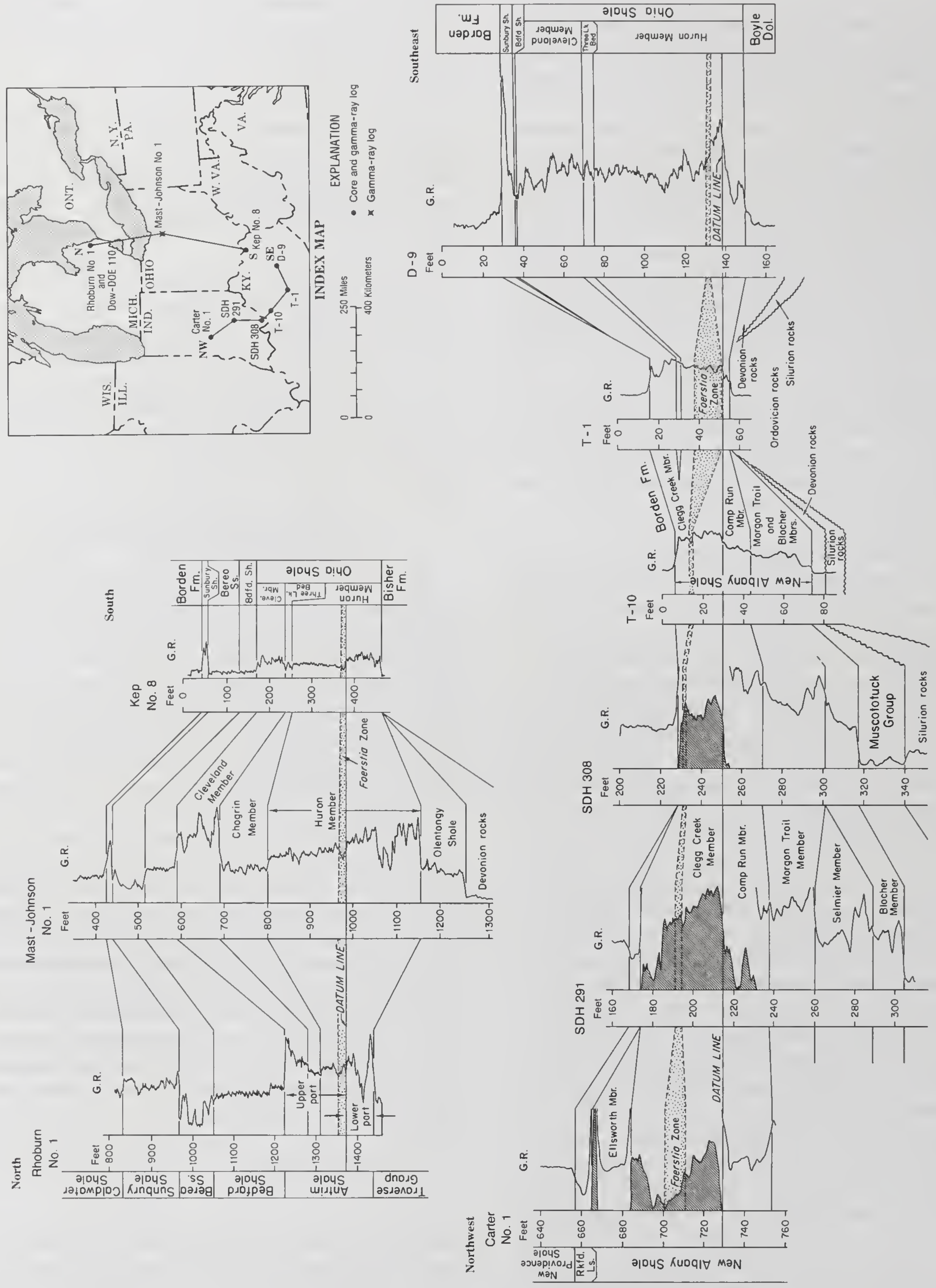


Figure 5. Stratigraphic cross sections showing correlations of the Devonian and Mississippian strata from the Michigan and Illinois Basins to the Appalachian Basin. The Rhoburn No. 1 well is an offset to the Dow-DOE 110 well, the well in which the *Foerstia* Zone was found. No horizontal scale. Vertical scale on the geophysical logs is depth in feet below the surface. Modified from Hasenmueller and others (1983a).

geophysical logs indicate that the various lithologies may grade vertically and laterally into one another with complex relationships. The lithology of the individual members and beds are herein described in stratigraphic succession from oldest to youngest.

Blocher (Shale) Member

The name Blocher Formation was introduced by Campbell (1946) to describe the brownish-black shale at the base of the New Albany that crops out near Blocher, Jefferson County, Indiana. The unit was redefined as a member of the New Albany by Lineback (1968, 1970).

The Blocher (Shale) Member is the basal member of the New Albany Shale in much of the Illinois Basin and consists of organic-rich, brownish-black (5YR 2/1)[3] to grayish-black (N 2), thinly laminated shale with calcitic and dolomitic laminae and beds. In Indiana, a thin, pyritic, phosphatic bed is present at the base. Carbonate is common in the lower part of the member, and thin pyrite-rich and pyritic sandstone laminae are common in the upper part.

The Blocher attains a maximum thickness of more than 80 feet in the subsurface in Hardin County, Illinois, and adjacent Kentucky (Cluff and others, 1981). Cluff and others (1981) noted that the exact lateral extent of the Blocher was problematic because the unit grades into the upper part of the underlying Lingle Formation. The western limit of the Blocher was therefore mapped as a vertical cutoff by Cluff and others (1981). In westernmost Kentucky, the contact of the Blocher with the underlying Middle Devonian carbonate rocks appears to be gradational (pl. 5). In the outcrop area in west-central Kentucky, Ettensohn and others (1991) identified an unconformity between the Blocher Member and younger members of the New Albany Shale. This unconformity extends into the subsurface of western Kentucky (fig. 4, pl. 5).

Conodonts indicate that the Blocher is mostly Middle Devonian (middle Givetian), although some beds are earliest Late Devonian (early Frasnian) (Collinson and others, 1967; Norby and Ettensohn, 1992). Studies of the conodont fauna suggest that the Blocher is equivalent to the upper part of the Lingle Formation, the Alto Formation, and the lowermost Upper Devonian strata in southern Illinois (Collinson and Atherton, 1975) (fig. 4).

Sylamore Sandstone Member

The Sylamore Sandstone Member was named for Sylamore Creek, Stone County, Arkansas (Penrose, 1891). The Sylamore crops out in small areas of western Illinois and is a thin, discontinuous, quartzose sandstone that generally varies in thickness from a few inches to 5 feet (Workman and Gillette, 1956). Sand-size grains are mostly quartz, but pyrite, calcite, and dolomite may be present. Where present in cores or well cuttings, pyrite grains are especially helpful in recognition and correlation of the Sylamore. Quartz grains are well rounded and fine- to medium-grained.

In areas of Illinois where the Blocher is not present, the Sylamore is the basal unit of the New Albany. The Sylamore rests unconformably on the Middle Devonian Lingle Formation, Cedar Valley Limestone, and Wapsipinicon Limestone. In western and central Illinois, the Sylamore unconformably rests on carbonate rocks that range from Late Ordovician to Middle Devonian (Collinson and Atherton, 1975) (fig. 4). The Sylamore typically grades upward into the overlying shale (Cluff and others, 1981).

The Sylamore may be correlative with the Hardin Sandstone of western Kentucky and Tennessee. It has not been recognized with certainty in the subsurface of Indiana, western Kentucky, and southeastern Illinois, although it may correlate with one or more thin sandy beds in the upper part of the Blocher or lower part of the Selmier in southeastern Illinois. Thin sandstone beds at the base of the Selmier in southeastern Indiana may be correlative with the Sylamore (Hasenmueller and Bassett, 1981).

Selmier (Shale) Member

Selmier Member was the name used by Lineback (1968) for the gray to black shale overlying the Blocher in the Berry Materials Company quarry, Jennings County, Indiana. The Selmier is recognized in the subsurface of southeastern Illinois and western Kentucky and has been recognized at a few localities along the outcrop belt of the New Albany Shale in west-central Kentucky (Lineback, 1970).

In this study, use of the name Selmier Member is proposed to replace the name Sweetland Creek Member in western Kentucky. The correlation of the Selmier from southern Indiana into the subsurface of Kentucky is substantiated herein (pl. 5). The name Selmier has been used previously in western Kentucky by Lineback (1970), Conkin and Conkin (1975), Beard (1980), Kepferle (1981), Conkin (1986), and Ettensohn and others (1989, 1991).

In the outcrop area of southeastern Indiana, the Selmier Member is predominantly a greenish-gray (5GY 6/1) to olive-gray (5Y 4/1) shale with thin beds and laminae of brownish-black shale, dolostone, limestone, and quartz sandstone. In the deep basin, the Selmier is generally dark-gray (N 3) to dark-olive-gray (5Y 3/2) and is only subtly different from the upper part of the Blocher. The dark shales in the Selmier are generally thickly or poorly laminated. The laminae commonly pinch and swell to form small irregular lenses. Most laminae are cemented by sparry calcite or pyrite; small pyrite nodules are common.

Thin beds and laminae of pyritic quartz sandstone and dolomitic sandstone are common at the base of the member in cores from southeastern Indiana and west-central Kentucky; however, the sandstone beds thin and become sparse in the deeper parts of the basin. Small concretions are present throughout, and large concretions are present near the top of the unit at the type locality.

The Selmier is 22 feet thick at the type locality and thickens southwestwardly to 126 feet in Posey County, Indiana. The maximum thickness of the Selmier mapped as Sweetland Creek by Schwalb and Norris (1980b) was 170 feet; however, the lower boundary of the member in Kentucky was revised by Lineback

---

[3] Color designations are from the "Rock-color Chart" (Geological Society of America, Rock-color Chart Committee, 1975).

(1980) to better conform with the interval of the shale mapped in southeastern Illinois, where the Selmier is more than 200 feet thick. The member thins to approximately 20 feet in central Illinois, where it is difficult to distinguish and is arbitrarily separated from the Sweetland Creek (Cluff and others, 1981).

In the deeper part of the Illinois Basin in southeastern Illinois, southwestern Indiana, and western Kentucky, the Selmier overlies the Blocher. The Selmier (Shale) Member is only partly equivalent to the Sweetland Creek Shale Member and is separated from that member by a vertical cutoff in western and central Illinois (Cluff and others, 1981) (pl. 5, A-A', D-D').

Sweetland Creek Shale Member

The name Sweetland Creek was used by Udden (1899) for beds of Devonian greenish-gray and brownish-black shales exposed along Sweetland Creek, Muscatine County, Iowa. Collinson and others (1967) proposed that the name Sweetland Creek Shale be restricted to the dominantly gray and green shale, which underlies the predominantly black Grassy Creek (Shale) Member and extends throughout much of the Illinois Basin.

The Sweetland Creek consists of alternating beds of dark-greenish-gray (5GY 4/1), greenish-gray (5GY 6/1), and grayish-green (10GY 5/2) shales with minor amounts of olive-gray (5Y 4/1) to olive-black (5Y 2/1) shale (Cluff and others, 1981). Interbedding between the olive-gray and greenish-gray shales is characteristic of the uppermost part of the member in western and central Illinois. The dominant lithofacies are indistinctly bedded, moderately bioturbated shale, and thickly or poorly laminated shale having few or no burrows.

Collinson and Atherton (1975) stated that the Sweetland Creek appears to be essentially continuous with the Selmier. In this report, use of the name Sweetland Creek is proposed in areas where the Blocher is not present. Where the Blocher is present in the central and southeastern portion of Illinois, the name Selmier is used (pl. 5, A-A', D-D', E-E').

The Sweetland Creek varies in thickness from a few inches in southwestern Illinois to as much as 50 feet in northwestern Illinois. An age range from early to middle Late Devonian is indicated by studies of the conodont fauna (Collinson and others, 1967).

Grassy Creek (Shale) Member

The Grassy Creek (Shale) Member was named by Keyes (1898) for Grassy Creek, a stream in Pike County, Missouri. As currently defined (Collinson and others, 1967), the name Grassy Creek is restricted to the dominantly black shale interval in the middle and upper part of the New Albany Shale.

In southern Illinois and western Kentucky the Grassy Creek consists of brownish-black (5YR 2/1) to grayish-black (N 2), finely laminated, pyritic, carbonaceous shale (Cluff and others, 1981). It is characterized by extraordinarily even, parallel, and closely spaced laminae. The Grassy Creek grades northward into less carbonaceous olive-black (5Y 2/1) to olive-gray (5Y 4/1) shales with thin interbeds of grayish-olive-green (5GY 3/2) to grayish-green (5G 5/2) mudstone (Cluff and others, 1981).

The predominant clay component is illite and the predominant detrital silt-sized components are quartz, feldspar, and coarse mica (Cluff and others, 1981). Dolomite and a very small amount of calcite are present locally as cement. Pyrite is abundant and is present along bedding planes as fine crystallites, framboids, flattened nodules, and lenses. The organic carbon content of samples from the member range from about 4 to 15 weight percent (Frost and others, 1985). Fossils are scarce and generally restricted to the greenish-gray shales; fossils include conodonts, fish skeletal debris, inarticulate brachiopods, and burrows.

The Grassy Creek attains a maximum thickness of about 160 feet in eastern Hardin County, Illinois, and adjacent Union and Crittenden Counties, Kentucky. In western Illinois, the undifferentiated Grassy Creek and Sweetland Creek interval attains a maximum thickness of about 140 feet. The Saverton, Louisiana, Horton Creek, and Hannibal thin and grade laterally eastward into the black shales of the upper portion of the Grassy Creek in extreme southeastern Illinois and adjacent western Kentucky.

The Grassy Creek usually conformably overlies the Sweetland Creek Shale or Selmier (Shale) Members. In areas where the Grassy Creek is not differentiated from the Sweetland Creek, the undifferentiated unit conformably overlies the Sylamore. Throughout most of the basin in Illinois the Grassy Creek is conformably overlain by the Saverton Shale Member or the undifferentiated Saverton and Hannibal Shale Members (pl. 5). In Jersey County, Illinois, and vicinity, where the Saverton is absent or very thin and unrecognizable, the Grassy Creek is overlain by the Louisiana Limestone Member or the Horton Creek Member. Across much of southeastern Illinois the Saverton and Hannibal shales are either very thin or absent or cannot be distinguished from the Grassy Creek. In these areas the Grassy Creek is overlain by the Chouteau Limestone or the Springville Shale.

In southeastern Illinois the base of the Grassy Creek is older than the base of the type Grassy Creek (Cluff and others, 1981). Similarly, the top of the Grassy Creek in extreme southeastern Illinois and adjacent western Kentucky appears to be younger, based on geophysical correlations, than the top of the type Grassy Creek (pl. 5). Locally in southern Illinois the uppermost black shales in the Grassy Creek are probably Kinderhookian in age (Cluff and others, 1981). The member is mostly equivalent to the Morgan Trail, Camp Run, and Clegg Creek Members in Indiana (fig. 4, pl. 5). In the type area, studies of the conodont faunas from the members that bracket the Grassy Creek indicate an early Late Devonian age (Collinson and others, 1962, 1967).

Morgan Trail Member

The Morgan Trail Member was named by Lineback (1968) for a roadside park near the type section, an outcrop in Scott County, Indiana. The Morgan Trail is characterized by brownish-black (5YR 2/1) to olive-black (5Y 2/1), finely laminated to fissile, siliceous shale with numerous pyritic and carbonate laminae and beds. It also contains a few thin beds of olive-gray (5Y 4/1) shale.

The Morgan Trail is 38 feet thick in Clark County, Indiana, and thins northward in Indiana. The Morgan Trail has not been mapped in the subsurface because it cannot be easily differentiated from the overlying Camp Run Member using geophysical logs or well cuttings (Hasenmueller, 1993).

Studies of conodont faunas from sections in the outcrop area of southeastern Indiana demonstrate that the member is latest Frasnian to early Famennian (Late Devonian) in age (Norby and Ettensohn, 1992). The Morgan Trail is in part correlative with the lower part of the Grassy Creek (Shale) Member in Illinois and western Kentucky (fig. 4, pl. 5).

Camp Run Member

The Camp Run Member, which overlies the Morgan Trail, was named by Lineback (1968) for the small creek that flows just north and east of the exposure in Clark County, Indiana. The Camp Run contains beds of bioturbated greenish-gray (5GY 6/1) and olive-gray (5Y 4/1) shale interbedded with brownish-black (5YR 2/1), organic-rich, pyritic, fissile shale. Carbonate laminae are present in cores, and dolomite concretions 2 to 3 feet in diameter are present in the brownish-black shale at the type locality.

The Camp Run has a uniform thickness of 24 to 28 feet in the subsurface of southeastern Indiana (Hasenmueller, 1982). The Camp Run is recognized in cores throughout central and southeastern Indiana; however, the interval is not differentiated on geophysical logs of wells in southwestern Indiana. The member correlates with part of the Grassy Creek in Illinois and Kentucky (fig. 4, pl. 5).

Clegg Creek Member

The Clegg Creek Member was first described by Lineback (1968) from roadcuts in Clark County, Indiana. It is commonly the upper member of the New Albany Shale in Indiana except in areas where the Ellsworth Member is present. The Clegg Creek overlies the Camp Run Member and underlies the Rockford Limestone (Kinderhookian) or Ellsworth. The Clegg Creek consists of brownish-black (5YR 2/1) to black (N 1), finely laminated to fissile, organic-rich, silty and pyritic shale. A few thin greenish-gray (5GY 6/1) shale beds are present at the top of the unit.

In Jackson, Scott, and northern Clark Counties, Indiana, the member is approximately 40 feet thick. Southward from Clark County the Clegg Creek thins to 22 feet in Harrison County; the thinning is in the upper part of the unit (Hasenmueller and others, 1983b). The member is as thick as 45 feet in Posey County.

The Clegg Creek has the highest organic content of all of the New Albany members in the eastern part of the basin. It contains an average of 12.6 weight percent organic carbon in cores from southeastern Indiana (Hasenmueller and Leininger, 1987). Core samples of the Clegg Creek interval from the Energy Resources of Indiana No. 1 Phegley Farms Inc. well in Sullivan County, western Indiana, contained an average of 9 weight percent organic carbon; core samples from the Anschutz Corporation No. 16-19 Voekel well in Dubois County in southwestern Indiana contained an average of 10 weight percent organic carbon.

Four thin, lithologically distinct beds have been recognized in the upper part of the Clegg Creek Member in southeastern Indiana. In ascending stratigraphic succession, they are: (1) Falling Run Bed, (2) Underwood Bed, (3) Henryville Bed, and (4) Jacobs Chapel Bed.

__Falling Run Bed__—The Falling Run was the name applied by Campbell (1946) to a phosphatic bed exposed along Falling Run Creek in New Albany, Floyd County, Indiana. The bed is 0.2 foot thick, and consists of phosphatic debris and nodules that are sparsely fossiliferous. The Falling Run Bed is recognized in cores and outcrops in the southeastern part of the basin. Phosphate nodules are also present at the same stratigraphic position in a core from Dubois County, southwestern Indiana (Hasenmueller, 1993).

The Falling Run, Henryville, and Jacobs Chapel Beds, are present at the top of the New Albany at two unusual exposures in southeastern Illinois: (1) Horseshoe, a narrow horst block along the Shawneetown Fault Zone in Saline County; and (2) Hicks Dome, a cryptoexplosion structure in Hardin County where the shale and other strata have been uplifted nearly 4,000 feet (Cluff and others, 1981).

__Underwood Bed__—The Underwood was named by Campbell (1946) for a fossiliferous, greenish-gray (5GY 6/1) shale exposed near Underwood, Clark County, Indiana. The Underwood Bed overlies the Falling Run and underlies the Henryville Bed. The bed is 0.4 foot thick and contains a conodont and scolecodont fauna of Kinderhookian age. The Underwood has been correlated with the lower part of the Hannibal Shale of Missouri and the Hannibal Shale Member of Illinois (Lineback, 1970).

__Henryville Bed__—The name Henryville was proposed by Campbell (1946) for the black shale exposed near Henryville, Clark County, Indiana. The bed consists of fissile, brownish-black (5YR 2/1) to black (N 1) shale that contains high concentrations of organic carbon and trace metals and is radioactive (Lechler and others, 1979). The bed thickness ranges from 0.4 to 1.7 feet in the outcrop area and attains a maximum of 4 feet in the subsurface of Indiana. Because of its thickness and radioactivity, the Henryville Bed can be traced on gamma-ray logs; it is recognized in the subsurface as far north as Hendricks County in central Indiana and is also present in Posey County in southwestern Indiana. Using gamma-ray logs, Cluff and others (1981) mapped the distribution of the Henryville Bed throughout much of southeastern Illinois. The bed has not been reported from the subsurface in western Kentucky, but it has been recognized in outcrop in Bullitt County, west-central Kentucky (Lineback, 1970; Conkin and Conkin, 1975).

__Jacobs Chapel Bed__—The name Jacobs Chapel was originally proposed by Campbell (1946) for greenish-gray (5GY 6/1) shale exposed near Jacobs Chapel church, Floyd County, Indiana. The bed is sparsely fossiliferous, glauconitic, greenish-gray shale and is the uppermost bed of the New Albany Shale in Indiana. In the outcrop area in southeastern Indiana, the bed is 0.2 to 0.6 feet thick. In the subsurface, the Jacobs Chapel and Falling Run Beds cannot be identified without cores. The bed was recognized in southeastern Illinois by Cluff and others (1981), who extended the use of the name Jacobs Chapel into that part of the state. The Jacobs Chapel is present in southern Jefferson and northern Bullitt Counties, Kentucky (Conkin and Conkin, 1972, 1975); however, the bed has not been recognized in westernmost Kentucky. Studies of the conodont fauna of the Jacobs Chapel Bed suggest that the age is similar to that of the middle and upper parts of the Hannibal (Rexroad, 1969).

Saverton Shale Member

The Saverton Shale was named by Keyes (1912a-b) for Saverton, Ralls County, Missouri. It is recognized as a distinct member in central and western Illinois, but is not differentiated from the overlying Hannibal Shale Member in areas where the intervening Louisiana Limestone and Horton Creek Members are both missing (fig. 4, pl. 5). The Saverton grades into the underlying and overlying formations and is perhaps the most difficult of all New Albany units to correlate regionally (Cluff and others, 1981). Both the upper and lower boundaries are diachronous becoming younger to the east and southeast in Illinois.

The Saverton consists of interbedded greenish-gray (5G 5/1), dark-greenish-gray (5G 4/1, 5GY 4/1), and olive-black (5Y 2/1) shales. Greenish-gray beds are nonlaminated, silty, and organic poor, whereas olive-black beds are laminated and contain less silt and more organic matter. Vertically stacked couplets of greenish-gray to olive-black shale about 1 to 2 cm thick comprise the lower part of the Saverton, and the upper part usually consists of massive, bioturbated, greenish-gray mudstone. The clay composition of the Saverton is primarily illite and chlorite; the silt fraction is predominantly quartz and feldspar. Calcite is very rare; dolomite is detected in variable quantities in almost all samples; pyrite content is very low.

The maximum thickness of the Saverton is 180 feet in western Illinois (Cluff and others, 1981). The member generally thins to the south and east as the lower portion grades laterally into the Grassy Creek Shale Member (Cluff and others, 1981). The Saverton thins to a feather edge along the Sparta Shelf.

The Saverton conformably overlies the Grassy Creek Shale Member and is conformably overlain by the Louisiana Limestone Member in Illinois. Where the Louisiana is absent, the top of the Saverton is considered to be the base of the upper limestone in the Horton Creek Member. Collinson and others (1967) reported that the conodont fauna of the Saverton indicate a Late Devonian age.

Louisiana Limestone Member

The Louisiana Limestone was named by Keyes (1892) for Louisiana, Pike County, Missouri. It covers an area 10 to 25 miles wide extending eastward from the Mississippi River into west-central Illinois. The Louisiana Limestone Member consists of light-gray to tan, wavy-bedded, micritic (lithographic) limestone interbedded with thin shales and dolostones. The limestone is commonly argillaceous and always extensively bioturbated.

The Louisiana commonly is less than 10 feet thick, but locally is 30 feet thick near the Mississippi River in Pike and Calhoun Counties, Illinois (Cluff and others, 1981).

The Louisiana conformably overlies and intergrades with the Saverton Shale Member. In certain small areas where the Saverton is absent or very thin and unrecognizable (for example, Jersey County and vicinity), the Louisiana directly overlies the Grassy Creek.

Throughout much of its extent in western Illinois the Louisiana is overlain by the Horton Creek Member. Where the contact is exposed in western Illinois, it is typically channeled and eroded; however, the contact is believed to be unconformable only locally along the flanks of the Lincoln Anticline.

Although nowhere abundant, a large variety of macrofossils are found in the Louisiana (Williams, 1943). Very small brachiopods and dwarfed crinoids are the dominant forms observed. Rare bryozoans, ostracodes, sponges, rugose and tabulate corals, pelecypods, gastropods, cephalopods, trilobites, and conodonts have also been found. Studies of conodont faunas demonstrated that the Louisiana is of latest Devonian age (Collinson and Atherton, 1975). The Louisiana correlates with the upper part of the Clegg Creek Member in Indiana (Lineback, 1970).

Horton Creek Member

The Horton Creek was named by Conkin and Conkin (1973) for the limestones, siltstones, sandstones, and shales previously included in the "Glen Park" Formation[4] in Illinois. The type section is in Horton Creek, Pike County, Illinois.

The Horton Creek Member contains siltstones, shales, sandy limestone, micritic limestone and dolostone, limestone conglomerates, and oolitic limestone. The siltstones and shales are greenish-gray (5GY 5/1) to dark-greenish-gray (5GY 4/1), highly bioturbated, generally unfossiliferous, and commonly calcareous and are similar to those in the Hannibal and upper part of the Saverton. Most of the widespread carbonate beds are gray to tan, argillaceous, sparsely fossiliferous micritic limestone and dolostone similar to the Louisiana Limestone Member.

The Horton Creek Member attains a maximum thickness of more than 60 feet in Bond and Montgomery Counties, Illinois, where it consists mostly of siltstone (Cluff and others, 1981). The limestones in the Horton Creek thin to the north and eventually pinch out in the Saverton and Hannibal interval. In the subsurface, the Horton Creek grades laterally eastward into the lower part of the Hannibal.

Conodont studies of outcrop samples of the Horton Creek suggest that the formation is earliest Mississippian and that the base coincides with the Devonian and Mississippian systemic boundary (Collinson and others, 1971). The age relationships in the subsurface remain problematic. On the basis of physical stratigraphic evidence, Cluff and others (1981) suggested that part or all of the shales and siltstones assigned to the Horton Creek are lateral facies equivalents of the upper part of the type Louisiana and the upper part of the Saverton, which are both Devonian. They concluded that the Horton Creek strata may be entirely Devonian or straddle the Devonian and Mississippian boundary.

---

[4] The name "Hamburg Oolite" was applied to exposures of oolitic limestone at Hamburg, Calhoun County, Illinois, by Weller (1914) (Atherton and others, 1975). Later, Moore (1928) included the "Hamburg" strata in the "Glen Park" (Atherton and others, 1975). The name "Hamburg" is preempted by the Hamburg Limestone or Dolomite of Cambrian age and is not used as a formal stratigraphic name in southwestern Illinois by the U.S. Geological Survey (Keroher and others, 1966) or the Illinois State Geological Survey (Rodney D. Norby, oral commun., 1993).

Hannibal (Shale) Member

The Hannibal was named by Keyes (1892) for exposures in the bluffs along the Mississippi River at Hannibal, Marion County, Missouri. The Hannibal Shale Member consists mostly of dark-greenish-gray (5GY 4/1, 5G 4/1), greenish-gray (5GY 6/1, 5G 6/1), grayish-olive-green (5GY 3/2), and dusky-yellow-green (5GY 5/2) mudstones and shales (Cluff and others, 1981). Calcareous mudstones are found locally and may grade laterally into the limestones in the Horton Creek or Louisiana.

The clay composition of the Hannibal is predominantly illite and chlorite. Silt is generally abundant and consists mostly of quartz, potassium feldspar, dolomite, and coarse-grained mica. Pyrite is a minor component and the organic carbon content is mostly less than 1 weight percent. The mudstones of the Hannibal are intensively bioturbated and have no laminae, bedding, or primary stratification.

At the type section and nearby areas, the basal part of the Hannibal rests on the Louisiana and may include strata equivalent to the Horton Creek Member. The Hannibal is not differentiated from the underlying Saverton and Horton Creek in much of northwestern and central Illinois, where the intervening Louisiana is absent (fig. 4). Where the Horton Creek is recognized, the Hannibal conformably overlies it. In parts of extreme western Illinois, the Hannibal is overlain conformably by the McCraney Limestone of the North Hill Group (Kinderhookian).

The Hannibal attains a maximum thickness of 110 feet in northeastern Macoupin County, Illinois. The Hannibal thins drastically but somewhat erratically to the north and west as a result of erosional truncation by the overlapping Burlington Limestone. It generally thins toward the southeast. Collinson and others (1971), citing conodont studies, concluded that the base of the Mississippian is positioned at or near the base of the Hannibal in western Illinois, making the Hannibal entirely Kinderhookian.

The Hannibal is recognized in western Kentucky where it overlies the Grassy Creek Member and is overlain by the Rockford Limestone. The unit was considered to be the lateral equivalent of the basal part of the New Providence Shale rather than part of the New Albany by Dever and McGrain (1969, fig. 7) and Shaver (1985). The Hannibal was recognized on geophysical logs from wells located in Daviess, Henderson, McLean, Ohio, and Union Counties, Kentucky, and was included as the uppermost member of the New Albany Shale in western Kentucky by Schwalb and Norris (1980a, 1980c-d). In this study, the Hannibal Member is designated as the uppermost member of the New Albany Shale in western Kentucky (pl. 5, F-F'). The Hannibal, as recognized in the subsurface of western Kentucky, probably includes strata equivalent to the undifferentiated Saverton and Hannibal Shale Members of Illinois.

The Hannibal in Kentucky is about 10 feet thick in a drill hole in McLean County (Schwalb and Norris, 1980a, d). In southwestern Kentucky thicknesses of about 10 feet and 35 feet were measured in cores from Calloway and Trigg Counties, respectively (Dever and McGrain, 1969, fig. 7).

Nutwood Bed—The Nutwood Member was named for the town of Nutwood, Jersey County, Illinois, by Workman and Gillette (1956) and is present across part of western Illinois where its maximum thickness is 40 feet. The Nutwood is a thin, olive-black (5Y 2/1), slightly silty, fissile shale with abundant *Tasmanites*. The Nutwood is designated a bed of the Hannibal Shale Member in this study.

Ellsworth Member

The name Ellsworth Shale was proposed by Newcombe (1932) for greenish-gray shale exposed in a quarry south of Ellsworth, Antrim County, Michigan. The Ellsworth was established as a formal member of the New Albany Shale in Indiana by Lineback (1968). The member locally overlies the Clegg Creek Member and underlies the Rockford Limestone. In some parts of Indiana, the Falling Run, Henryville, and Jacobs Chapel Beds are included in the Ellsworth Member.

The Ellsworth is greenish-gray (5G 5/1 to 6/1) and dark-greenish-gray (5GY 4/1) shale. The unit is intensely bioturbated and is noncalcareous to slightly calcareous. In the northern part of the Illinois Basin the member consists of an upper greenish-gray shale interval and a lower thinly interbedded greenish-gray and brownish-black shale interval.

Typically, the Ellsworth Member is not recognized in Indiana southeast of a northeast-trending arc from Warrick County to the northeastern corner of Jackson County. It thickens to the southwest toward the depocenter, attaining 40 feet in Posey County. The Ellsworth attains a maximum thickness of more than 80 feet in Benton County, Indiana, in the northernmost part of the basin (Bassett and Hasenmueller, 1980).

GAS PRODUCTION

By Terence Hamilton-Smith, Nancy R. Hasenmueller, Wesley S. Boberg,
Zinta Smidchens, and Wayne T. Frankie

Introduction

The gas content of the New Albany Shale in the Illinois Basin has been estimated by the Devonian Shale Task Group of the National Petroleum Council Committee on Unconventional Gas Sources (Bookout, 1980) to be 86 TCF. This estimate was based on the calculation of gross shale volume and an average gas content of 0.62 standard cubic feet of gas per cubic foot of shale. This average gas content was based on off-gassing[5] studies of the various lithologies of the New Albany shale from six cores from wells in the Illinois Basin (Snyder and others, 1978). Off-gassing measurements were obtained from core that had been sealed in supposedly air-tight canisters. Because of sample leakage, the estimated gas content may have substantially underestimated the subsurface gas content of the shales. Proportional to area, the gas content of the New Albany Shale is comparable to that of the Devonian shales of the Michigan and the Appalachian Basins (Oliver and others, 1989). However, recent exploration for Devonian shale gas has been much less active in the Illinois Basin than in either the Michigan or the Appalachian Basins.

The average initial potential (IP) of a New Albany Shale gas well is calculated to be 187 MCFGPD, based on data from 60 fields in the Illinois Basin (table 1, pl. 6). The IP of a New Albany Shale gas well is generally significantly greater than the initial production into a gas pipeline. In 1890, the Meade County fields of Kentucky had an initial production rate that was only 20 percent of the total IP of the same wells (Jillson, 1922). General experience with New Albany Shale gas production, and with comparable gas production in the Appalachian Basin, suggests that initial gas production is followed by a substantial decline to relatively low rates of flow. Compression may be required in order to raise the well-production pressure above the back pressure of the local gas pipeline. Experience also shows that these relatively low rates are very stable, and may be maintained for many years.

Gas was first produced commercially from the New Albany Shale in the Illinois Basin with the drilling of the Moreman well near Brandenburg in Meade County, Kentucky, in 1863 (Jillson, 1922). However, Jillson (1922) reported drilling in the Meade County gas field as early as 1858, presumably for local consumption. In 1888, the Rock Gas Company was formed to pipe produced gas to Louisville, and an 8-inch pipeline with a capacity of 10 million cubic feet of gas per day (MMCFGPD) was completed in 1890, collecting gas from the 30 best of the over 100 field wells (Jillson, 1931).

"Gas springs" were first noted in the bed of the Ohio River in Indiana in 1870 (Collett, 1879); in 1885, drilling for New Albany Shale gas began in Harrison County, Indiana. Wells drilled at Tobacco Landing near the gas springs yielded gas from the New Albany and salt brine from the underlying carbonate rock of the Muscatatuck Group (Devonian). The gas was used for evaporating the brine for salt and in the hydraulic lime industry in the area. By 1925, seven fields were producing gas from the New Albany Shale in Harrison County (Sorgenfrei, 1952).

This early phase of New Albany Shale gas exploration and production ended because of significant regional competition from an abundant supply of gas produced from Mississippian carbonate reservoirs in eastern Kentucky and adjacent West Virginia. In 1906, the United Fuel Gas Company opened a gas transmission line along the Big Sandy River valley in eastern Kentucky (Jillson, 1922). In 1907, the Louisville Gas and Electric Company, which had taken over the interests of the Rock Gas Company, opened up a 12-inch gas pipeline from Martin County in eastern Kentucky to Louisville. This was followed in 1918 by a second 10-inch gas line from Martin County to Lexington and Frankfort by the Central Kentucky Natural Gas Pipe Line Company (Jillson, 1919).

Since the initial development, gas has been discovered in the New Albany in at least 40 fields in Kentucky and 19 fields in Indiana (table 1, pl. 6). Production of gas from the New Albany Shale was recently extended to Illinois, with the drilling of the Hux Oil Corporation No. 13-1 Racop-Benson Community well, the discovery well of the Russellville Field in Lawrence County, in 1989 (table 1, pl. 6).

Maps showing the distribution of natural-gas pipelines in Illinois and Indiana have been previously published at a scale of 1:500,000 (Meents, 1968; Keller, 1991). A map showing the distribution of natural-gas pipelines in Kentucky by the Kentucky Department of Economic Development in 1984 was published at a scale of 1:1,169,723.

Kentucky

Information concerning the early discovery and production of gas from the New Albany Shale of western Kentucky is summarized in Jillson (1919, 1922, 1931). Most of this early production came from gas fields immediately south of the Ohio River in Meade, Bullitt, and Breckinridge Counties. A discussion of more recent gas production from the New Albany Shale in western

---

[5] The term off-gas (also known as released gas or headspace gas) refers to the gas released from subsurface samples that were sealed in airtight canisters shortly after their recovery. Interpretations based on the composition of off-gas assume that the off-gas that accumulates in the canister has the same composition as the gas originally present in the shale.

Table 1. New Albany Shale gas fields in the Illinois Basin, and locations and average initial potential (IP) of the wells.

State	Field Name	County	Location	Total Wells	Wells with IP Data[*]	Average IP (MCFGPD)	NAS Discovery Date
			T.-R.				
Illinois	Russellville	Lawrence	4N, 11W	4	3	120	1989
Indiana	Bramble	Daviess	4N, 5W	1	1	250[†]	1973
	Coalmont West	Sullivan	9N, 8W	1	1	115	1988
	Corydon	Harrison	3S, 3-4E 4S, 4E	14	13	111	1923
	Dickeyville	Warrick	4S, 7W	3	1	4,400[†]	1989
	Duff	Dubois	2S, 6W	1	1	8[†]	1990
	Elizabeth	Harrison	5S, 5E	1	0	NA[‡]	1925
	Glendale	Daviess	2N, 6W	1	1	750	1940
	Hardinsburg	Washington	1S, 2E	1	1	25[†]	1981
	Iva East	Pike	1N, 6-7W	2	2	37[†]	1988
	Laconia	Harrison	4-6S, 4E	92	38	229	1915
	Linton	Greene	7N, 7W	4	4	114	1989
	Loogootee North	Martin	3-4N, 4W	12	12	707	1948
	Lyons	Greene	6N, 6W	1	0	NA[†]	1988
	New Boston	Harrison	5S, 5E 6S, 4-5E	6	1	500	1885
	New Middletown	Harrison	4S, 4E	27	22	121	1923
	Paxton West	Sullivan	7N, 9W	3	2	50[†]	1985
	Rosewood	Harrison	5-6S, 5E	20	2	225	NA
	Rosewood North	Harrison	5S, 5E	4	0	NA	NA
	Yankeetown	Warrick	7S, 8W	1	1	1,200[†]	1989
			Carter Quad.				
Kentucky	Bells Run	Ohio	N-32	1	1	2	1980
	Bon Ayr	Barren	G-42	NA	0	NA	1929
	Brandenburg Stn.	Meade	R-41	3	0	NA	1961
	Buck Fork Pond	Todd	F-27	1	1	2	1983
	Buie Knob	Trigg	F-23	1	1	6	1979
	Cadiz East	Trigg	E-21	3	2	254	1976
	Cave Run Consol.	Daviess	O-32	1	0	NA	1938
	Clark	Christian	G-25,26	7	7	84	1977
	Claymour	Todd	E-28,29,30	38	34	23	1979
	Cloverport	Breckinridge	Q-35	NA	0	NA	NA
	Concord Church S.	Ohio	L-33	NA	0	NA	1971

---

[*] Number of New Albany Shale wells in the field with IP data.

[†] Shut in.

[‡] Not available.

Table 1. New Albany Shale gas fields in the Illinois Basin, and locations and average initial potential (IP) of the wells—Continued.

State	Field Name	County	Location	Total Wells	Wells with IP Data	Average IP (MCFGPD)	NAS Discovery Date
			Carter Quad.				
Kentucky	Crofton	Christian	G-25	2	2	51	1979
	Doe Run	Meade	R-41,42	65	0	500[§]	1858
	Duncan Ridge	Logan	F-30	1	0	NA	1978
	Exie	Green	H-48	1	1	250	1979
	Horse Branch	Ohio	L-34	1	1	1	1938
	Lost Run	Breckinridge	O-38	1	1	45	1939
	Macedonia E.	Christian	H-23	2	1	80	1989
	Meadow	Bullitt	S-43	25	0	15-300[‖]	1892
		Hardin	R-43				
		Jefferson	S-43,44				
			T-44				
	Meredith	Grayson	K-39	1	1	20	1942
	Muldraugh	Meade	R-42	3	3	282	1929
	Nash	Butler	J-37	11	10	336	1982
		Grayson	J,K-37				
	Park City	Barren	H-42	NA	0	NA	1937
	Pleasant Ridge N.W.	Daviess	N-30	1	0	NA	1980
	Post	Grayson	L-37	3	2	53	1973
	Ready	Grayson	K-37	3	3	149	1974
	Ready North	Grayson	K-37	2	2	110	1975
	Rockhaven	Meade	R-42,43	45	0	500[§]	1858
	Shrewsbury	Butler	J-37	70	67	147	1939
		Edmonson	J-37,38				
		Grayson	J,K-37,38				
			K-39				
			L-38				
	Shakertown	Logan	E-35	1	1	250	1952
	Sisk School	Hopkins	I-24	1	0	NA	1977
	Unnamed	Caldwell	H-22	1	0	NA	NA
	Unnamed	Larue	L-46	1	0	NA	1946
	Unnamed	Logan	F-30	1	0	NA	1978
	Unnamed	Todd	F-28	1	1	2	1983
	Unnamed	Trigg	E-21	1	0	NA	1976
	Unnamed	Warren	H-38	1	0	NA	1969
	West Point	Hardin	R-43	NA	0	NA	1890
	Windyville	Edmonson	I-38	1	1	30	1981
	Whittinghill	Grayson	K-36	1	1	5	1980

[§] Average open flow for all Meade County gas wells (Jillson 1931).

[‖] From Jillson (1931).

Kentucky, including a partial summary of wells drilled between 1919 and 1978, was compiled by Schwalb and Norris (1980e-f). Of the 106 gas wells reported by Schwalb and Norris (1980f), 81 had shows of gas, but never produced from the New Albany Shale. Only 25 wells listed by Schwalb and Norris (1980f) had metered gas test or production data, and only nine of these wells were completed as New Albany Shale gas producers. Nine wells tested gas from the shale but were subsequently abandoned, and the remaining seven wells were drilled as injection wells for a gas storage project. The extension of New Albany Shale gas production to Grayson, Christian, Todd, and Trigg Counties was documented by Schwalb and Norris (1980e-f), who also reported unsuccessful shale tests in Breckinridge and Ohio Counties.

Meade County Fields

The Meade County gas fields cover some 4,000 to 8,000 productive acres in Meade and Hardin Counties of western Kentucky (Jillson, 1931) and include the Doe Run, Rockhaven, Muldraugh, and Brandenburg Station Fields (Sutton and Wagner, 1930). Gas production is related to a structure consisting of "two small domes on two roughly parallel cross folds running northeast from the Dry Ridge anticline" (Jillson, 1922, p. 53). In the particular case of the Muldraugh Field, gas production is related to a domal structure described by A. L. Bryant of the Louisville Gas and Electric Company as "a plug of brecciated Knox Dolomite of Cambrian and Early Ordovician age which had pierced the overlying Middle and Late Ordovician section prior to Silurian deposition of a fringing biostromal reef" (Black, 1986, p. 151).

Gas production was generally attributed to a zone some 7 feet below the top of the New Albany Shale (Jillson, 1922), which presumably would be in the upper part of the Grassy Creek Member. However, only five of the 12 individual field wells described by Jillson (1931) produced gas from the New Albany Shale. These five wells had an average IP of 75 MCFGPD. The Louisville Gas and Electric No. 1 Pete Sheeron well produced gas from an 11-foot zone in the New Albany Shale, 4 feet below the top of the formation. The Louisville Gas and Electric No. 1 William Tindall well produced gas from an 11-foot zone in the New Albany, 2 feet below the top of the formation. The Louisville Gas and Electric No. 1 G. A. Corbett well produced gas from an 8-foot zone, 4 feet below the top of the unit. The seven other wells described by Jillson (1931) produced gas from the underlying Devonian "Corniferous" limestone,[6] at an average IP of 1,466 MCFGPD. The striking contrast between the average IP values of wells known to have been productive from the New Albany Shale and of wells that produced from the underlying Devonian limestone suggests that production from these fields cannot be attributed to the New Albany Shale alone.

Drilling in Meade County began in 1858, culminating in approximately 100 field wells by 1890. Production declines led to the installation in 1891 of two 150-horsepower compressors. Between 1890 and 1921, decline curves for the Meade County gas fields reflect the early performance of the field (fig. 6). In 1890, the 30 best wells individually tested a total IP of 10,000 MCFGPD, but produced only 2,000 MCFGPD on line (Jillson, 1922, p. 53).

The most productive well in the early history of the Meade County fields had an IP of 2,000 MCFGPD, at a "rock pressure" of 51 pounds per square inch (psi) (Jillson, 1922, p. 53). A few years later, the new record IP was 4,500 MCFGPD (Jillson, 1931), and nine other wells had an average IP of 1,500 MCFGPD per well. The range of rock pressures in older wells was 22 to 64 psi and an average well produced 500 MCFGPD at a rock pressure of 50 psi. Later wells showed a higher range of rock pressures from 121 to 184 psi (Jillson, 1931), having an average working reservoir pressure of 85 psi. Although this average pressure was somewhat higher than the 64 psi average reported for the older wells, an average well still produced 500 MCFGPD (Jillson, 1931). A small part of the Meade County fields was known for sour gas[7] (Jillson, 1931).

Meade County gas initially was used to evaporate brine produced from the same wells. Jillson (1922, p. 53) noted as a peculiarity of the fields that "salt water appeared in all the wells, either at the time of drilling or very shortly thereafter." One well is cited as having produced water for 35 years. In general, the New Albany Shale produced gas, and the "Corniferous" limestone produced both gas and water. Drillers' logs from the Harrington No. 1 and the Louisville Gas and Electric No. 1 Pete Sheeron wells indicate gas production from the New Albany Shale, together with salt-water production from the underlying Devonian strata (Jillson, 1931). The Ivyton Oil and Gas No. 1 J. W. Rhodes and the Louisville Gas and Electric No. 1 William Tindall well logs note gas production from the New Albany Shale with no water influx. However, records for the Louisville Gas and Electric No. 1 G. A. Corbett well indicate gas production in an interval of the New Albany immediately overlying a zone within the shale that produced salt water, indicating that water was produced from the New Albany Shale in some wells.

Well files at the Kentucky Geological Survey document significant contributions of both gas and water from the Middle Devonian limestone in the Muldraugh Field, together with gas production from the New Albany Shale. The Louisville Gas and Electric No. 2 R. Beeler well had an IP of 400 MCFGPD from the New Albany Shale, but "at 5 feet in the Corniferous water filled to 60 feet in the hole" (unpublished data on file at the Kentucky Geological Survey). The Hume and Steele No. 1 G. Chapman well had an IP of 265 MCFGPD from the New Albany Shale at a rock pressure of 45 psi, and the Louisville Gas and Electric No. 1 Withers well had an IP of 180 MCFGPD from the New

---

[6] In Meade County well logs the "Corniferous" is a Devonian limestone usually present immediately below the New Albany Shale (Jillson, 1931). In one well log the top of the "Corniferous" was 25 feet below the base of the New Albany Shale. The "Corniferous" limestone ranged from 5 to 83 feet in thickness in the Meade County well logs (Jillson, 1931).

[7] Gas containing hydrogen sulfide.

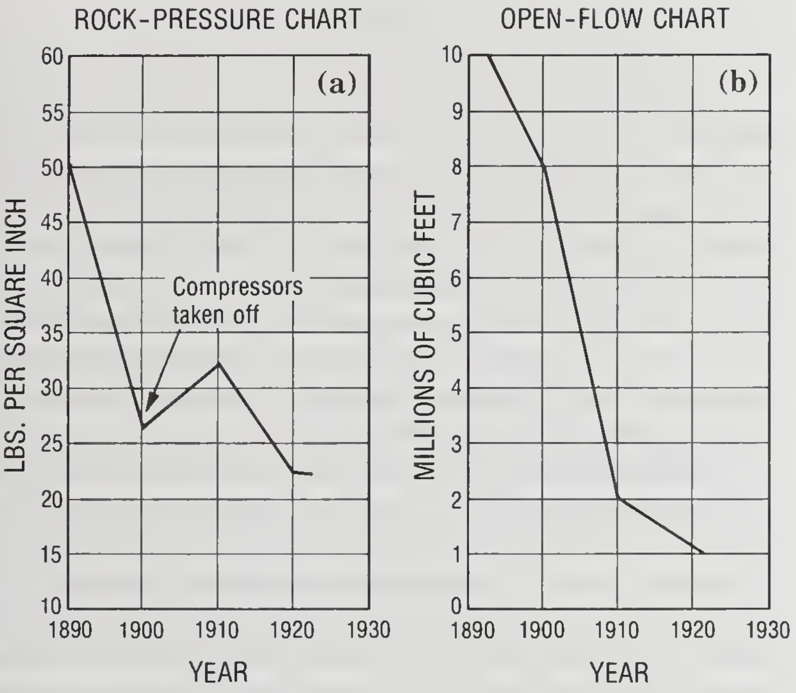


Figure 6. Graphs showing rock pressure-decline and production-decline curves, Meade County fields, Kentucky, from 1890 to 1921. (a) Rock pressure-decline curve, and (b) production-decline curve. Modified from Jillson (1922).

Albany Shale at a rock pressure of 58 psi. However, the Hume and Steele No. 1 O. Chapman well had an IP of 2,439 MCFGPD from the "Corniferous" at a "rock pressure" of 85 psi (Jillson, 1922), and the Hume and Steele No. 2 W. Chapman well had an IP of 1,000 MCFGPD from the "Corniferous."

Meadow Field

The Meadow Field is located in Bullitt, Hardin, and Jefferson Counties, west-central Kentucky (pl. 6). At its maximum areal extent the productive area of the field covered nearly 8 square miles and included between 25 and 40 wells, all of which produced gas for domestic consumption. A review of the sparse production data from the Meadow Field by Jillson (1931) suggested IP rates in the range of 15 to 300 MCFGPD from New Albany Shale, at depths from 225 to 300 feet. Partial records of 23 wells suggest that drilling took place between 1890 and 1924. Of 15 wells for which data were available, the productive life ranged from 2 weeks to 34 years, the average being 14 years. Abandonment of the wells was frequently the result of water influx. The Lynds Dodge farm well initially produced abundant gas from a depth of 250 feet, but was abandoned after it filled with salt water when the well was deepened to 1,700 feet.

The driller of the B. F. Birdwell farm well found water beneath the New Albany Shale and "cased it off" (Jillson, 1931, p. 179). Gas was subsequently produced for 12 to 14 years, until water encroachment resulted in the abandonment of the well.

Shrewsbury Consolidated Field

The Shrewsbury Consolidated Field is located in Grayson, Butler, and Edmonson Counties, western Kentucky (pl. 6), and includes the Shrewsbury, Nash, Ready, Ready North, and Leitchfield South Fields in a productive area of over 25,000 acres. Gas production has been obtained from a number of reservoirs, including the Mississippian Big Clifty Sandstone Member of the Golconda Formation (Jackson Sandstone), Beaver Bend Limestone, Ste. Genevieve Limestone, St. Louis Limestone, Salem Limestone, and Warsaw Limestone, and the Devonian and Mississippian New Albany Shale. Depth of production varies from about 300 feet for the Big Clifty to over 1,800 feet for the New Albany. In contrast to the New Albany Shale gas fields to the north, no water production has been associated with the gas production of the Shrewsbury Consolidated Field.

The first wells in what was to become the Shrewsbury Consolidated Field were drilled in 1918 in the Leitchfield South Field, for local gas sales to Leitchfield (fig. 7). In 1930, the Louisville Gas and Electric Company obtained leases for 18,000 acres in the area and subsequently drilled six additional wells. In 1938, the Shrewsbury Field was discovered southwest of the Leitchfield South Field. All of the early gas production was from Mississippian reservoirs, and it was not until 1939 that the New Albany Shale gas pay was discovered. In 1940, the city of

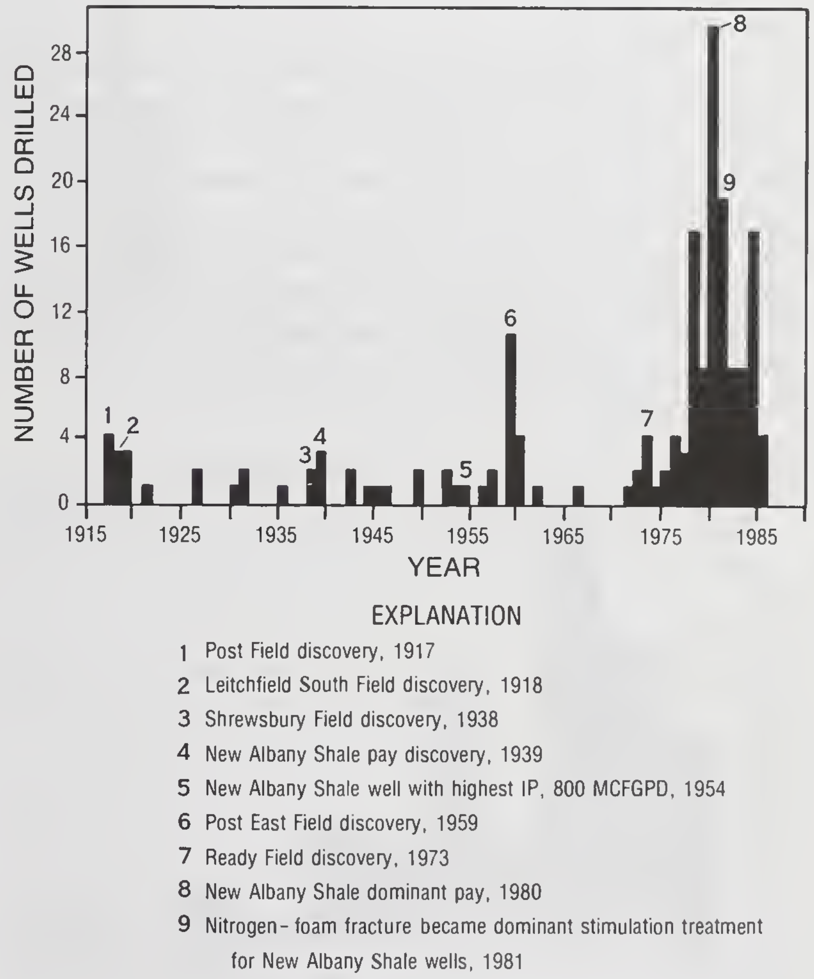


Figure 7. Drilling history for the Shrewsbury Consolidated Field area, western Kentucky. Includes producing wells, dry holes, and abandoned wells in all gas-producing horizons.

Leitchfield installed a pipeline and gathering system for the Shrewsbury Field. The most productive New Albany Shale gas well discovered to date in the Shrewsbury Consolidated Field, the J. W. Drilling No. 3 Walter Phelps was drilled in 1954 and had an IP of 800 MCFGPD.

Drilling in the Shrewsbury Consolidated Field accelerated significantly in the late 1970s with the increase in the market price of gas. By 1980, New Albany Shale completions accounted for most of the new wells drilled, and by 1981 nitrogen foam-fracture stimulations had largely replaced the older gelatinated nitroglycerine shot treatments. Drilling declined in the 1980s with the decrease in the market price of gas; no wells were drilled in the field between 1986 and 1990.

IP values for New Albany Shale wells in the Shrewsbury Consolidated Field, based on well records at the Kentucky Geological Survey, commonly range from 120 to 180 MCFGPD (fig. 8). A selection of individual well data for New Albany Shale wells stimulated with gelatinated nitroglycerine shot (table 2) and for New Albany wells stimulated by nitrogen-foam fracturing (table 3) indicates that nitrogen-foam fracturing is the more beneficial method. An approximately log-normal distribution of IP after stimulation is indicated and shows a primary mode between 120 and 180 MCFGPD (fig. 8).

Other Discoveries

The Cadiz East Field in Trigg County (pl. 6) was discovered in 1976 when the Vincent and Reynolds No. 1 Ira Humphries well was drilled. In the Clark Field of northern Christian County (pl. 6), New Albany Shale gas was discovered as deeper pay production in 1977 during the drilling of the Orbit Gas Company No. 1 King-Badgett well. The Claymour Field in Todd County (pl. 6) was discovered in 1979 by the drilling of the Huff Drilling Company No. 1 Richard Mallory well (Duffy and Schwalb, 1979). No water production has been associated with the production of gas from the New Albany Shale in these areas.

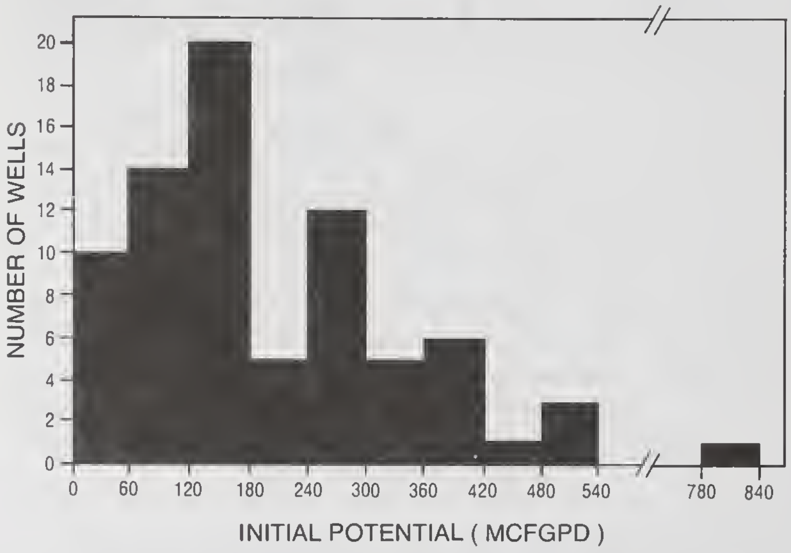


Figure 8. Initial-potential (IP) histogram for New Albany Shale wells in the Shrewsbury Consolidated Field, western Kentucky.

Indiana

Much of the available commercial production data for the fields in Harrison and Martin Counties in Indiana was summarized by Sorgenfrei (1952). Bassett and Hasenmueller (1977, 1978, 1981) reported New Albany gas production from seven fields in Harrison County, the Loogootee North Field in Martin County, and the Bramble and Glendale Fields in Daviess County (pl. 6). Unpublished information relating to the gas production from these fields is on file in the Energy Resources Section of the Indiana Geological Survey and in a manuscript entitled "Natural Gas Fields in Indiana" by Sullivan (in preparation).

The history of completions of New Albany Shale gas wells in Indiana peaked in 1927 (fig. 9a). Since 1980 several small New Albany gas fields have been discovered in southwestern Indiana in Sullivan, Greene, Pike, Dubois, and Warrick Counties (pl. 6).

The depth to the top of the New Albany in the producing gas fields varies from 300 feet in the Rosewood Field in Harrison County to 3,340 feet in the Yankeetown Field in Warrick County. The range of average reported IP values for the fields varies from 8 MCFGPD in the Duff Field, Dubois County, to 4,400 MCFGPD in the Dickeyville Field, Warrick County (pl. 6). However, the majority of the available IP values for the New Albany Shale in Indiana ranged from 30 to 200 MCFGPD (fig. 9b).

Harrison County Fields

To date, much of the gas production from the shale in Indiana has been from Harrison County (pl. 6). The majority of the completed gas wells in Harrison County were drilled from the late 1800s to the mid-1900s. The wells were 300 to 800 feet deep and were drilled by the Kentucky Heating Company (which later became the Louisville Gas and Electric Company) and the Railroaders' Gas Company (now the Indiana Utility Corporation).

The Kentucky Heating Company was the main operator when drilling for gas began in 1885 in the Tobacco Landing area of the Laconia Field. The gas was piped across the Ohio River to Louisville, Kentucky. The estimated open flow for the Tobacco Landing and the adjacent Meade County, Kentucky, wells in late 1889 was 2,300 MCFGPD (Sorgenfrei, 1952). The Kentucky Heating Company was the main operator until 1920, when the Railroaders' Gas Company was organized. Railroaders' Gas further explored and developed the Laconia Field, which by 1924 was producing 7,500 MCFGPD. A maximum number of 40 wells were producing in 1928. Dry holes and pipeline costs forced Railroaders' Gas into bankruptcy and into the receivership of the Indiana Utility Corporation in 1929. Soon afterward, increased gas production from West Virginia and eastern Kentucky made Indiana production unprofitable for the Louisville Gas and Electric Company, and by 1931 all of their New Albany Shale gas production had been shut in (Sorgenfrei, 1952). Indiana Utilities continued as the only major operator in Harrison County, with a small drilling program of five to six wells per year. Their total production also slowly increased until 1935 when maximum production was attained. An estimated 5 billion cubic feet (BCF) of gas was produced from the Harrison County gas fields, 1 BCF by Louisville Gas and Electric and 4 BCF by Indiana Utilities (Sorgenfrei, 1952).

An unpublished 1926 report of Railroaders' Gas Company wells in the New Middletown and Laconia Fields indicated rock pressure between 48 and 169 psi, and open-flow rates ranging from 27 to 1,361 MCFGPD (Sorgenfrei, 1952) (table 4). Available IP values for the Harrison County fields on file at the Indiana Geological Survey ranged from as low as 24 MCFGPD to as high as 1,100 MCFGPD (Hasenmueller, 1989a).

Gas was produced from two intervals in the New Albany Shale, with the best production reported from a zone 15 to 30 feet below the top of the formation (Sorgenfrei, 1952) in the organic-rich shale of the Clegg Creek Member. Sorgenfrei (1952) also noted that a zone 20 to 30 feet above the base of the New Albany, which in Harrison County corresponds to the position of the Morgan Trail Member, also yielded gas in some wells. Interpretation of data on file at the Indiana Geological Survey indicates that a large part of the production in the county was from the upper interval of the New Albany Shale. However, Sorgenfrei (1952, p. 7) cited R. E. Henshaw of Louisville Gas and Electric Company to the effect that "all of the gas production in the area was not true shale production. The drillers unknowingly had tapped the then unexplored Corniferous limestone for their gas and were calling it production from the New Albany Shale."

All of the Harrison County wells produced salt water along with the gas, sometimes in amounts sufficient to cause the flow of gas to cease (Sorgenfrei, 1952). The average life of a commercial well in Harrison County was approximately 20 years. Some wells lasted for a much longer period of time, but the production was not of commercial quantity. The majority of the wells that were shut in were still capable of producing 10 to 30 MCFGPD; however, because of the salt water, the wells could not be operated economically (Sorgenfrei, 1952).

Although these gas fields are now almost totally abandoned, there are still several wells in the fields that are not listed as abandoned in the files in the Energy Resources Section at the Indiana Geological Survey. Part of the largest field, Laconia, is being used by the Ohio Valley Transmission Corporation for underground gas storage in the Devonian and Silurian carbonate rocks underlying the New Albany Shale (Dawson and Carpenter, 1963).

Loogootee North Field

The Loogootee North Field in Martin County yielded gas from as many as 12 of 19 total wells, but as of 1981 it contained only one domestic gas well for home use. Gas was first produced from a well in 1902; however, data are lacking for the producing formation, the completion interval, and the total depth of this well. The other 11 wells in the field were drilled between 1948 and 1953 and are known to have produced gas from the New Albany Shale. Gas was found in the upper 50 feet of the shale at a depth of about 1,500 feet and the maximum gas flow was from a zone about 30 feet from the top of the shale (Sorgenfrei, 1952). At a depth greater than approximately 50 feet into the shale, salt water was generally encountered (Sorgenfrei, 1952).

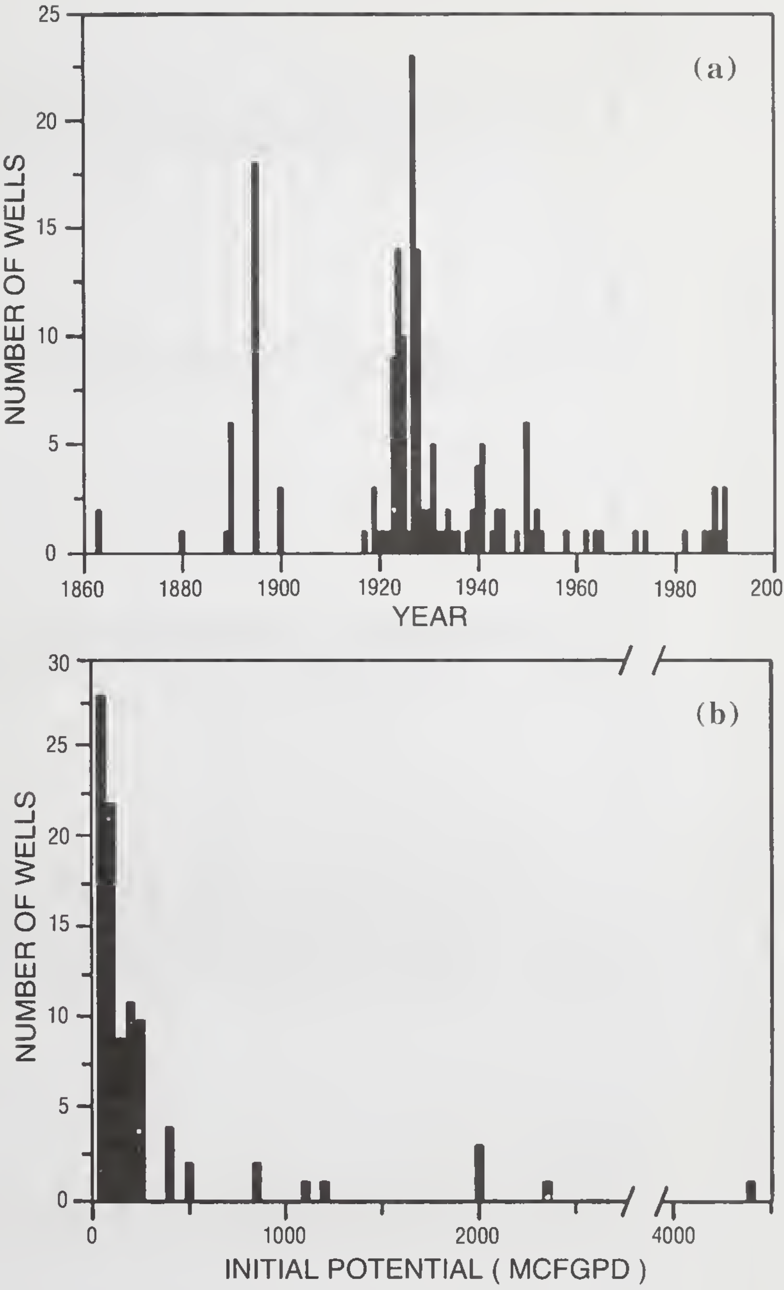


Figure 9. Well-completion history for the New Albany Shale in Indiana. (a) Well-completion history, and (b) initial-potential (IP) histogram. Modified from Hasenmueller and others (1991).

The field wells were cased to the Rockford Limestone, drilled into the shale or the underlying Devonian limestone, and completed open hole with gelatinated nitroglycerine shot stimulation. After the wells were shot, the open-flow rates reportedly increased threefold to fourfold (Sorgenfrei, 1952). The last three wells drilled in the field were completed only in the upper 40 feet of the shale, thus avoiding most of the salt water. IP values ranged from 200 to 2,000 MCFGPD and the average IP was 780 MCFGPD (Bassett and Hasenmueller, 1977). A structure map of the Loogootee North Field on top of the New Albany Shale shows a structural depression (Sorgenfrei, 1952).

Table 2. Gelatinated nitroglycerine shot stimulation data for the New Albany Shale in the Shrewsbury Consolidated Field, western Kentucky.

Well Name	Carter Coordinates	IP Before (MCFGPD)	Depth (Feet)	Nitroglycerine (Qt)[*]	IP After (MCFGPD)	Completion Date
Equitable No. 1 Johnson	4-J-38	show	1,520-1,649	260	80	5/81
Equitable No. 1 Moon	3-J-38	none	1,502-1,602	200	150	9/80
Equitable No. 2 Likens	4-J-38	none	1,544-1,666	244	120	10/81
Equitable No. 1 Mattingly	5-J-38	show	1,551-1,671	240	150	8/81
Equitable No. 1 Stewart	4-K-38	none	1,588-1,688	200	70	10/80
Equitable No. 3 Seaton	7-K-38	none	1,560-1,690	260	70	11/80
Equitable No. 1 Clagett	3-K-38	none	1,440-1,573	240	26	5/80
Equitable No. 2 Kerr	9-K-38	24	1,361-1,461	200	160	5/81
Compass No. 3 Davis	11-K-38	0	1,516-1,626	207	30	9/82
Compass No. 4 Davis	11-K-38	4.5	1,528-1,681	290	30	10/81
Equitable No. 1 Kerr	12-K-38	show	1,540-1,670	260	120	12/80
Equitable No. 1 Mudd	12-K-38	show	1,540-1,660	240	20	4/81
Equitable No. 1 Morrison	13-K-38	none	1,534-1,654	240	90	1/81
Equitable No. 1 Decker	14-K-38	5	1,532-1,672	280	125	12/80
Equitable No. 1 Lashley	14-K-38	none	1,520-1,650	260	150	11/80
Equitable No. 4 Seaton	14-K-38	none	1,517-1,647	260	100	8/81
Equitable No. 2 Seaton	14-K-38	5	1,589-1,709	260	100	8/80
Equitable No. 1 G. Seaton	16-K-38	0	1,542-1,662	240	60	12/80
Equitable No. 1 Nash	17-K-38	0	1,610-1,730	240	50	1/81
Equitable No. 2 Nash	17-K-38	show	1,594-1,714	240	120	5/81
Equitable No. 1 Coy	18-K-38	show	1,495-1,625	260	125	7/80
Compass No. 1 Woosley	17-K-38	show	1,540-1,670	260	7	3/81
Equitable No. 3 Seaton	14-K-38	none	1,590-1,690	200	120	10/80
Equitable No. 2 Seaton	7-K-38	20	1,546-1,646	180	91	8/80
Bartley No. 2 Burton	23-L-38	show	1,562-1,732	1700 lb	22	12/80
Equitable No. 1 Logsdon	8-K-38	none	1,566-1,646	160	30	10/80
Equitable No. 1 D.Seaton	8-K-38	20	1,546-1,679	265	137	7/80
Equitable No. 1 Willis	8-K-38	none	1,559-1,679	240	42	9/80
Equitable No. 1 N. Seaton	7-K-38	10	1,550-1,675	250	130	10/80
Equitable No. 1 Johnson	22-K-38	40	1,440-1,586	260	89	5/80
Young No. 1 Dinwiddie	10-K-38	31	1,535-1,635	800 lb	500	5/39
LG&E No. 1 Cockreil	5-K-39	NA	1,617-1,678	30	80	5/42
LG&E No. 1 Seaton	18-K-38	37	1,449-1,511	500 lb	508	6/31
JW Drilling No. 3 Phelps	18-K-38	NA	1,432-1,480	60	800	1954
Compass No. 2 Dinwiddie	10-K-38	20	1,510-1,660	260	NA	5/83
Leitchfield No. 1 Dinwiddie	9-K-38	show	1,472-1,602	850 lb	320	10/39
Equitable No. 1 Likens	4-J-38	show	1,565-1,695	260	115	6/80

[*] Quarts unless otherwise noted.

Table 3. Nitrogen-foam fracture stimulation data for the New Albany Shale in the Shrewsbury Consolidated Field, western Kentucky. Stimulation includes 500 gallons of 15 percent hydrochloric acid and 60,000 pounds of sand proppant.

Well Name	Carter Coordinates	IP Before (MCFGPD)	Depth (Feet)	Nitrogen (MSCF)	IP After (MCFGPD)	Completion Date
Equitable No. 2 Johnson	7-J-38	show	1,518-1,543	495	150	11/81
Equitable No. 1 Willis	1-J-37	20	1,541-1,682	500	500	5/82
Equitable No. 1 Davis	4-J-38	show	1,474-1,566	495	200	5/82
Equitable No. 2 Davis	4-J-38	40	1,574-1,672	420	120	8/82
Equitable No. 1 Moorman	4-J-38	show	1,521-1,589	531	150	12/81
Equitable No. 1 Likens	18-K-37	show	1,822-1,870	445	150	1/82
Equitable No. 3 Likens	24-K-37	0	1,797-1,906	500	100	6/82
Equitable No. 1 Renfrow	7-K-38	show	1,590-1,655	720	120	10/81
Equitable No. 22 Willis	2-J-37	none	1,622-1,748	514	250	6/83
Equitable No. 1 Forsythe	22-K-37	show	1,573-1,607	465	250	9/83
Equitable No. 4 Likens	23-K-37	40	1,776-1,906	450	150	6/84
Equitable No. 1 Tomes	3-J-37	50	1,551-1,638	474	450	7/84
Equitable No. 1 Cruze	22-K-37	show	1,595-1,713	378	250	4/84
Equitable No. 1 McConnell	7-J-38	show	1,771-1,869	339	250	4/84
Equitable No. 1 Woosley	9-J-37	25	1,532-1,574	468	250	9/83
Equitable No. 5 Likens	18-K-37	NA	1,799-1,923	420	200	11/83
Equitable No. 1 Woosley	3-J-37	10	1,577-1,666	348	400	1/84
Equitable No. 1 Moeller	2-J-37	25	1,540-1,679	330	200	11/83
Equitable No. 2 Moeller	2-J-37	show	1,660-1,761	393	250	6/84
Equitable No. 2 Forsythe	21-K-37	25	1,518-1,602	369	400	1/84
Equitable No. 2 Woosely	3-J-37	15	1,553-1,654	423	300	7/84
Equitable No. 4 Willis	21-K-37	show	1,724-1,788	360	200	7/84
Equitable No. 1 Haynes	1-J-37	25	1,570-1,655	336	250	1/85
Equitable No. 1 Knight	1-J-37	show	1,545-1,599	390	250	3/85
Equitable No. 3 Willis	2-J-37	show	1,575-1,663	354	200	6/84
Equitable No. 1 Burge	7-J-37	show	1,821-1,905	375	400	10/84
Equitable No. 2 Tomes	3-J-37	20	1,710-1,774	324	375	9/84
Equitable No. 4 Moeller	2-J-37	show	1,718-1,791	336	400	10/84
Equitable No. 1 Warren	8-J-37	5	1,572-1,628	348	250	11/84
Equitable No. 1 Myer	8-J-37	5	1,582-1,667	348	300	11/84
Equitable No. 2 Burge	8-J-37	show	1,816-1,922	332	250	4/85
Equitable No. 1 Wells	8-J-37	show	1,575-1,671	348	300	4/85
Equitable No. 1 Dotson	4-J-37	25	1,820-1,907	360	350	4/85
Equitable No. 1 Huff	8-J-37	show	1,613-1,712	384	250	6/85

In 1951, the Loogootee Brick and Tile Factory used 720 MCFGPD supplied by three wells in the Loogootee North Field. The gas was sweet and nonodorous and had a British Thermal Unit (BTU) rating of 980 BTU/CF (Sorgenfrei, 1952).

Daviess County Fields

Two one-well New Albany Shale gas fields, the Glendale and Bramble Fields, are located in Daviess County. The Glendale Field well, the Norris No. 1 Connelly, located in Sec. 33, T.2N., R.6W., was drilled in 1940 and had a commingled IP of 750 MCFGPD from both the New Albany Shale and the underlying carbonate rock of the Muscatatuck Group (Bassett and Hasenmueller, 1981). The shale production was from a 7-foot-thick zone near the base of the Morgan Trail Member (Bassett and Hasenmueller, 1981). This well is now abandoned.

The Bramble Field well, the Finch No. 1 Knepp, located in Sec. 28, T.4N., R.5W., was drilled in 1973. The well was an open-hole completion and tested 250 MCFGPD natural flow from the entire shale interval (1,675 to 1,790 feet). Gas has never been produced from this field, and the well is now classified as a shut-in gas well. In 1977 a production test was conducted in the Bramble Field well; this test indicated a potential of 262 MCFGPD. Gas from the well was analyzed and had a BTU rating (wet basis) of 1,002 BTU/CF. In two additional wells drilled in the vicinity of the Bramble well, gas was not reported and no completion was attempted in the New Albany (Bassett and Hasenmueller, 1981).

Post-1980 New Albany Shale Gas Wells

Most of the post-1980 New Albany Shale well completions are in small fields located in south-central and southwestern Indiana (table 1, pl. 6). The more recently discovered fields are located along a trend from Warrick to Greene and Sullivan Counties and contain from one to four wells.

The Coalmont West, Iva East, and Linton Fields overlie buried Silurian pinnacle reefs along the Terre Haute Bank. In the Linton Field, there is approximately 175 feet of structural closure on the top of the Muscatatuck Group (Droste and Shaver, 1980). Fracturing resulting from differential compaction and flexure of the New Albany over the buried reefs may be the cause of shale gas reservoir development at these localities. The average field IP ranges from 37 MCFGPD in the Iva East Field to 115 MCFGPD in the Coalmont West Field (table 1, pl. 6). The four gas wells in the Linton Field in Greene County had IP values ranging from 75 to 195 MCFGPD.

Illinois

Although gas production was not reported from the Illinois part of the basin until 1989, numerous gas shows have been reported in southeastern Illinois. In 1989, gas was discovered in the New Albany Shale in the Russellville Field of Lawrence County (table 1, pl. 6) with the workover of the Hux Oil Corporation No. 13-1 Racop-Benson Community well. Following stimulation, the New Albany produced 60 MCFGPD at a flowing tubing pressure of 845 psi from a perforated interval at a depth of 2,750 to 2,788 feet. Stimulation consisted of a nitrogen-foam fracture, using 160 thousand standard cubic feet (MSCF) of nitrogen, 3,000 gallons of gelled potassium chloride water, and 13,100 pounds of sand proppant through 38 perforations at one-foot intervals. This well was tested by the company and had an effective permeability thickness of 3.4 millidarcy-feet.

A step-out well, the R & M Farms et al. No. 7-1, was completed in the New Albany Shale between 2,724 and 2,766 feet; the well had an IP of 199 MCFGPD. Stimulation consisted of a nitrogen-foam fracture using 1,250 MSCF of nitrogen, 249 gallons of gelled potassium chloride water, and 40,000 pounds of sand through 42 perforations at one-foot intervals. A second step-out well, the Hux Oil Corporation No. 12-1 R & M Farms, had an IP of 100 MCFGPD using a 48/64 choke with a 1,050 psi shut-in casing pressure from a perforated New Albany Shale interval at a depth of 2,698 to 2,738 feet. Stimulation consisted of a nitrogen-foam fracture through 78 perforations at a depth of 2,698 to 2,738 feet, using 855 MSCF of nitrogen, 19,320 gallons of gelled potassium chloride water, and 70,000 pounds of 20/40 sand proppant. The Hux Oil Corporation No. 9-1 Seward well was abandoned after a hydraulic fracture stimulation with 20,000 gallons of water and 22,000 pounds of 20/40 sand proppant, which resulted in only a slight show of gas and production of 100 barrels of water per day (BWPD).

Reservoir Character

Introduction

The New Albany Shale consists of interbedded dark-gray and medium-greenish-gray shale, with less abundant beds of argillaceous dolomite in the lower part of the section. Porosity of the New Albany Shale in a core from Christian County, Kentucky, varies from 0.5 to 3.1 percent, averaging 1.8 percent. Porosity of the New Albany Shale in a core from Sullivan County, Indiana, varies from 0.6 to 9.3 percent, averaging 4.0 percent (Kalyoncu and others, 1979). Matrix permeability values in a core of the New Albany Shale from Clark County, Indiana, varied from 2.5×10^{-6} to 1.9 millidarcies and had a geometric average of 1.4×10^{-3} millidarcies (Zielinski and Moteff, 1980).

Gas Adsorption

Natural gas storage in shales may occur either as free gas in open pore space or as adsorbed gas on internal surfaces within the shale. A common assumption that is supported by experimental data is that gas adsorbed on solids occurs as a closely packed layer of molecules, one molecule thick (Adam, 1941). If chemical reaction between the gas and the solid surface is neglected, adsorption appears to be the result of van der Waals forces that produce condensation in liquids. As the adsorbed gas has a density much greater than that of the associated free gas, the process of gas adsorption is capable of storing much greater volumes of natural gas than can be accommodated in the open pore space.

Natural gas adsorption in the Ohio Shale of the Appalachian

Table 4. Rock pressure and initial-potential (IP) data for Railroaders' Gas Company wells in the New Middletown and Laconia Fields, Harrison County, Indiana. Modified from Sorgenfrei (1952).

Well Name	**Initial Pressure (psi)**	**IP (MCFGPD)**
New Middletown Field		
Mauch No. 1	126	220
Shop Lot No. 1	NA	119
Bickell No. 1	105	75
Gelback No. 1	98	27
L. Kannapel No. 1	96	46
G. Kannapel No. 1	96	92
Stiener No. 1	92	50
Laconia Field (Dogwood area)		
Blake No. 1	NA	59
Blake No. 2	NA	46
Berkhems	72	495
Melton No. 1	70	1,361
Cotner No.1	74	28
Laconia Field (Tobacco Landing area)		
Couzens No. 1	50	80
Couzens No. 3	50	65
Couzens No. 4	50	37
Couzens No. 5	50	37
Couzens No. 6	50	20
Couzens No. 7	50	24
Couzens No. 8	50	65
Couzens No. 9	50	40
Dodd No. 1	50	168
Conway No. 1	50	150
Crosier No. 1	48	122
Crosier No. 2	169	145
Average for wells	**74**	**149**

Basin has been studied in detail. Schettler and Parmely (1993) have concluded that the Devonian shales have an average of 5 percent porosity and approximately 50 percent of the gas stored in shales is in the adsorbed state. This means that estimates of the gas content based on the porosity alone will severely underestimate the gas actually present. Currently, the best technique to measure the gas storage capacity in shales is by the determination of the isotherm, or determination of gas content as a function of pressure at a specific temperature.

Natural gas adsorption not only affects storage capacity, but also the deliverability of shale reservoirs. Free methane in open pore space has a molar concentration that is linearly related to pressure, so that any pressure decrease in shale is accompanied by a proportional decrease in the free gas concentration. In contrast, the relationship between pressure and the molar concentration of adsorbed methane is strongly nonlinear. At relatively high pressures, an incremental pressure decrease does not result in significant gas desorption, and most of the gas released from shale is from open pore space. At relatively low pressures an incremental pressure decrease results in desorption of more methane than is released directly from open pore space. Release of the bulk of the adsorbed gas is accomplished only by decreasing the reservoir pressure to the lowest practical levels. At such low pressure levels, gas desorption rates should be stable for extended periods of time (Schettler and others, 1977).

Desorption has a number of practical effects on gas production from shale reservoirs. First, the production decline curve is characterized by a steep initial decline, as the free gas in the fracture system and adjacent open pores is depleted. This is followed by an extended period of production, often lasting many years, at reduced rates controlled by gas desorption in equilibrium with free gas in the fracture spaces (Schettler and Parmely, 1987a). Second, the composition of the gas changes with time, as ethane and heavier hydrocarbons are more strongly adsorbed than methane, so that the produced gas becomes richer in heavier hydrocarbons with extended production (Schettler and Parmely, 1987b). Finally, cumulative gas production will be significantly greater than estimates based on open shale porosity.

Analyses of gas adsorption in the New Albany Shale are relatively rare, but suggest the same characteristics as measured in the Ohio Shale. Gas storage in the New Albany Shale occurs both as free gas in open pore space and as adsorbed gas on internal rock and kerogen surfaces (Frost and Thomas, 1978; Thomas and Frost, 1978). Methane adsorption isotherms at 28°C were obtained for New Albany Shale core samples from Sangamon, Effingham, and Tazewell Counties, Illinois, and from Christian County, Kentucky. The samples showed that between 30 and 80 percent of the methane in the shale was adsorbed gas, with the fraction of adsorbed gas showing a strong dependence on pressure. At pressures above 40 atmospheres (588 psi) most of the methane in the shale was in the form of free gas. At pressures below 20 atmospheres (294 psi) most of the methane was adsorbed gas. These data support the interpretation that production characteristics of New Albany Shale gas wells will be generally similar to Ohio shale gas wells, with an initial rapid decline followed by stable production at significantly lower rates, maintained by gas desorption.

Fractures

The low level of matrix permeability measured in the New Albany Shale indicates that natural fractures must be present for the shale to act as an effective gas reservoir. Sorgenfrei (1952, p. 24) commented that

> the shale is a hard, brittle, competent formation. Whenever it is subjected to deformation forces, such as folding and faulting, causing stress upon the formation, fracturing results. The fracturing gives the rock permeability and porosity and permits the shale to act as a reservoir rock. The non-fractured adjacent New Albany Shale and the overlying soft, incompetent Borden Shales form an ideal cap rock for the gas.

In 1980, the Anschutz Corporation No. 16-19 Voelkel well was drilled in Sec. 19, T.2S., R.5W. in Dubois County, Indiana, and a good show of gas was reported from the New Albany Shale. The shale was at a depth of 2,078 to 2,250 feet. The upper 30 feet of the Clegg Creek Member was cored, and the brownish-black shale in this interval contained natural fractures.

Fractures in a core of the New Albany Shale from the Energy Resources of Indiana No. 1 Phegley Farms Inc. well in Sullivan County, Indiana, were described by Kalyoncu and others (1979). Twenty-one fractures were described over an interval of 104 feet. They were mainly vertical, but some had dips as low as 80 degrees. The strike of the fractures was predominantly northwest-southeast and a small secondary mode trended slightly to the north of east-west. Joint orientations in outcrops of the New Albany Shale in Indiana are parallel to this secondary east-west trend of fractures in the Phegley Farms core (Carr, 1981, fig. 31). A more detailed study of joint orientations in outcrops of the New Albany Shale of Indiana by Ault (1990) confirmed a dominant orientation trending east-northeast (76 degrees), and a subordinate orthogonal mode.

Fractures in a core of the New Albany Shale from the Orbit No. 1 Clark well in Christian County, Kentucky, were described by Miller and Johnson (1979). Natural fractures were regular planar subvertical features striking northwest-southeast. They generally were filled with calcite, or less commonly with pyrite, and had apertures as great as 3.0 millimeters. In the vertical plane, these fractures were commonly continuous for 1 or 2 feet, succeeded by subparallel fractures offset from each other at their terminations.

Contemporary maximum horizontal stress is oriented east-northeast in the northern Illinois Basin, changing to east-west in the south (Nelson and Lumm, 1984, 1987; Zoback and Zoback, 1989). This suggests that the primary joints mapped by Carr (1981) and Ault (1990) are neotectonic in origin, resulting from erosional unloading in the current stress regime (Engelder, 1982). The secondary east-west joint trend in the New Albany Shale of the Phegley Farms core also may be of neotectonic origin, while the northwest-southeast primary joint trend in both the Phegley Farms and the Christian County cores presumably is inherited from Alleghenian tectonism.

The fractured character of the New Albany Shale reservoir is suggested by the geophysical logs from the Equitable Resources No. K10001 Hopkins well in Hopkins County, Kentucky (fig. 10). Gas entry into the wellbore at about 3,945 feet is indicated by an anomaly in the temperature log. At that depth, the neutron log indicates a high-porosity anomaly, interpreted as the effect of a thin gas-filled fracture. This well tested 42 MCFGPD from the New Albany Shale, but was completed as a Mississippian Cypress Sandstone oil well farther uphole.

Water Production

Water production associated with gas production from the New Albany Shale is variable across the Illinois Basin. Unfortunately, a search of the files of the three state surveys has not uncovered any specific information on water composition, disposal practices, or production rates. In his review of gas production from the New Albany Shale of Harrison County, Indiana, Sorgenfrei (1952, p. 7) stated that "in all the gas wells completed, there has been salt water produced along with the gas. Occasionally the water occurs in such abundance that it either drowns out the well or a pump must be set to pump it out." Well abandonment in Harrison County because of water problems occurred mainly at gas flow rates of less than 30 MCFGPD (Sorgenfrei, 1952). In the Loogootee North Field, Martin County, Indiana, the three best wells were completed in the upper 40 feet of the New Albany Shale. Six other wells were either drilled deeper into or through the shale to the carbonate rocks of the Muscatatuck Group, resulting in an abundance of gas together with an overabundance of salt water. Attempts to plug off the water were unsuccessful (Sorgenfrei, 1952).

Water encroachment presented problems in the production of gas from the Meadow Field and wells of the Meade County fields of northwestern Kentucky. Where fragmentary well records permit evaluation, water is generally reported to be associated with the limestone beneath the New Albany Shale. Farther to the south in Kentucky, water was not reported in any of the gas wells drilled in the New Albany Shale of the Shrewsbury Consolidated Field.

Gas Composition

The ratio of methane to total hydrocarbons in natural gas from the New Albany Shale includes both gas released from core and gas produced from wells (table 5). These data are drawn from various sources, including Claypool and Threlkeld (1978), Claypool and others (1978), Snyder and others (1978), Zielinski (1978), and Zielinski and others (1978). The high degree of variability, particularly in the contrast between wet gas released from core and relatively dry gas produced from wells, suggests compositional fractionation during production, as previously suggested for the Ohio Shale by Schettler and Parmely (1987a). The significant content of ethane and heavier hydrocarbons also suggests that New Albany Shale gas is associated with oil generation (Schoell, 1983). This interpretation is supported by the local production of small amounts of oil from the New Albany Shale in 12 fields in Allen, Simpson, and Barren Counties, southern Kentucky (Nuttall, 1989a), and by the intermittent production of oil from the New Albany Shale in the Louisville Gas and Electric No. 1 Seaton well of the Shrewsbury Consolidated Field.

The interpretation of New Albany Shale gas as associated with oil production is also supported by carbon isotope data for methane (table 5). Schoell (1983, p. 2231) suggested that "the first methane formed from cracking reactions in petroleum should be about -50 to -60 per mil," which corresponds well to the measured range for New Albany Shale methane of -53 to -56 per mil. Lineback (1980, p. 29) commented that the isotopic analysis results "indicate that the gases are of low-grade thermal origin with no significant contribution of bacterial gas."

Measurements of carbon dioxide concentrations in New Albany Shale gas are available from produced and headspace gas (table 5). Analyses of New Albany Shale gas produced from wells showed very low carbon dioxide concentrations ranging from 0 to 0.1 percent; however, New Albany Shale headspace gas obtained from cores has somewhat higher carbon dioxide concentrations, ranging from 1.3 to 5.1 percent. High carbon dioxide concentrations appear to be related to areas of water production associated with New Albany Shale gas production (table 5).

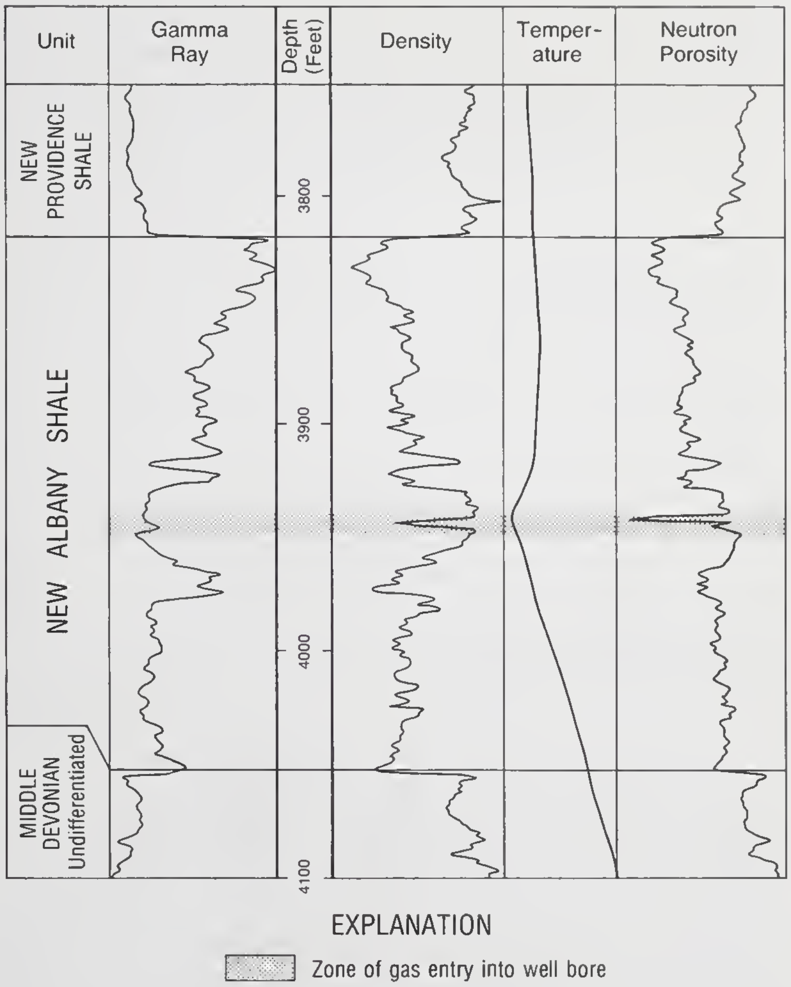


Figure 10. Zone of gas entry from fractured New Albany Shale in Equitable Resources No. K10001 Hopkins, Hopkins County, Kentucky.

Stimulation

New Albany Shale gas wells generally require some form of stimulation for economic production. The traditional manner of stimulating New Albany Shale wells has been the use of a gelatinated nitroglycerine charge exploded in the wellbore in an open hole across the anticipated productive interval. New Albany gas wells in the Shrewsbury Consolidated Field of western Kentucky were stimulated by gelatinated nitroglycerine explosion ("shot") (table 2). The stimulations were performed in the open-hole intervals indicated. The amount of gelatinated nitroglycerine used is generally measured in quarts, but occasionally in pounds. After stimulation IP values are increased an average of 12 times, ranging between 1.4 and 36 times. All of the wells in the Loogootee North Field were shot with nitroglycerine, which generally increased the initial gas flow rate threefold or fourfold

Table 5. Composition of gases from the New Albany Shale.

State	County	Location	Well Name	$C_1/(C_1$ to $C_5+)$	$\delta^{13}C$ (‰)[*]	CO_2 (%)
			Headspace Gas Analysis			
Illinois	Effingham	31-9N-4E	Tri Star Prod. No. 1-D Lancaster (02IL, I-1)	0.75		
Illinois	Tazewell	8-23N-2W	Northern Illinois Gas No. 1 MAK (06IL)	0.49		2.3
Illinois	Wayne	17-3S-8E	Jenkins No. 1 Simpson (13IL)	0.68	-52.5	1.3
Illinois	Wayne	34-1S-7E	Hobson Oil No. 2 Taylor (12IL)	0.74		
Indiana	Clark	CMG[†] 283-2N-7E	IGS SDH[‡] No. 290 Clark Co. State Forest	0.76	-55.8	1.7
Indiana	Sullivan	14-6N-10W	Energy Res. Ind. No. 1 Phegley Farms (01IN, P-1)	0.77		5.1
Kentucky	Christian	12-G-25	Orbit No. 1 Clark (01KY)	0.73		
			Produced Gas Analysis			
Indiana	Daviess	28-4N-5W	Finch No. 1 Knepp	0.96		
Indiana	Dubois	19-2S-5W	Anschutz No. 16-19 Voelkel	0.99		
Kentucky	Christian	10-G-25	Orbit No. 1 King-Badgett	0.97		0.1
Kentucky	Grayson	18-K-37	Equitable No. 1 Likens	0.88		0.0
Kentucky	Grayson	18-K-38	Cappetro No. 1 Richards	0.92		
Kentucky	Meade	21-R-42	Muldraugh Field (1931)	0.99		
Kentucky	Trigg	21-E-21	Hoffman No. 1 Major	0.99		0.1

[*] per mil or parts per thousand.

[†] CMG = Clark Military Grant.

[‡] SDH = Indiana Geological Survey drill hole.

(Sorgenfrei, 1952). Available data for New Albany Shale wells in Indiana stimulated with gelatinated nitroglycerine shot (table 6) and for New Albany wells stimulated by nitrogen-foam fracturing (table 7) indicate that nitrogen-foam fracturing is the more beneficial.

During the 1980s, gelatinated nitroglycerine shot stimulations of New Albany Shale gas wells were replaced by nitrogen-foam fracture stimulations. Since 1981 most New Albany gas wells in the Shrewsbury Consolidated Field of western Kentucky had nitrogen-foam fracture stimulation (table 3). These stimulations were performed through perforations in well casing. The first step of stimulation was generally the circulation of 500 gallons of 15 percent hydrochloric acid solution. This step was followed by injecting a mixture of nitrogen-foamed water under pressure sufficient to hydraulically fracture the formation. The nitrogen-foamed water also carried sand to prop the newly created fractures open during production. In most wells, 60,000 pounds of sand were used as the proppant. The amount of water used is not always documented in well completion reports. Where it is mentioned, between 180 and 270 barrels of potassium chloride water were used to foam the nitrogen. After the nitrogen-foam fracture stimulation, IP values increased an average of 18 times, ranging between 2.5 and 50 times.

Devonian Shale Gas Production in the Michigan and Appalachian Basins

Antrim Shale

Gas was first noted in the Antrim Shale in 1912 but was not developed commercially until 1940 with the discovery of the Otsego Field in Otsego County, Michigan (Ells, 1978; Maslowski, 1991). Commercial production was first documented in 1947, when an annual yield of about 30,000 MCFG was reported from two Antrim Shale wells (Maslowski, 1991). By 1978 cumulative production from the Otsego Field had reached over 600,000 MCFG, from a total of nine field wells (Ells, 1978). The Algonac Field was discovered in St. Clair County in 1947; this field was abandoned in 1951 after the drilling of two Antrim Shale wells and the cumulative production of 9,000 MCFG (Ells, 1978; Maslowski, 1991). The Dow Chemical Company conducted an engineering evaluation of the Antrim Shale in Sanilac County from the early 1950s to 1965, designed to assess the potential of the shale as a source of both gas and oil. In 1965 the Chester Field was discovered, and by 1978 almost 900,000 MCFG had been produced from 16 wells in the Antrim Shale (Ells, 1978; Maslowski, 1991). The Sanilac County project was revitalized in the 1970s by Dow Chemical with the support of DOE; reports summarizing this project were compiled by Ells (1978), Matthews and others (1978), and Young (1978). In 1977 three additional Antrim Shale fields were discovered, including the Dover Field and the Otsego Lake Field of Otsego County, and the Mayfield Field of nearby Grand Traverse County (Ells, 1978). Antrim Shale development accelerated in the mid-1980s; drilling doubled each year after 1986 to peak at 891 Antrim Shale wells completed in 1990 (Oliver and others, 1989; Kelly, 1992). Most of this recent activity has taken place in and near Otsego County, and is associated both with the pipelines and the structures of the previously developed Silurian reef trend (Ells, 1978; Kelly, 1992). By January 1, 1991, the Antrim Shale was producing 123,000 MCFGPD from about 1,050 wells (Kelly, 1992).

A typical Antrim Shale well produces about 75 MCFGPD ranging between 5 MCFGPD and over 1,000 MCFGPD (Lang and Oliver, 1991; Kelly, 1992). A study of three Antrim Shale fields having production data showed little decline in gas production rate over time periods as great as 12 years (Lang and Oliver, 1991). Initial water production is typically greater than 100 BWPD, declining to 20 or 30 BWPD as the fracture system near the well is dewatered (Oliver and others, 1989; Lang and Oliver, 1991). Cumulative gas recoveries over a 30-year period have been between 300,000 and 1,200,000 MCFG per well (Oliver and others, 1989). Break-even gas production from Antrim Shale wells was considered to be about 50 MCFGPD under prevailing economic conditions in the late 1980s (Oliver and others, 1989).

Well stimulations, which are generally required for effective gas production, traditionally consisted of gelatinated nitroglycerine shots; nitrogen-foam fracture stimulations began to be more widely used, however, in 1978 after experimental investigations were supported by the DOE (Ells, 1978; Lang and Oliver, 1991). Simulation of production from the Muskegon Development No. B1-17 well in Otsego County suggested that fracture treatment removed severe wellbore damage, but otherwise did not stimulate the well (Lang and Oliver, 1991). Analyses of gas produced from the Antrim Shale show concentrations of carbon dioxide between 2 and 10 percent, averaging between 5 and 6 percent (McGuire and Oliver, 1988; Lang and Oliver, 1991). This concentration of carbon dioxide has led to corrosion problems, particularly in subsurface pumps installed to lift water. Gas samples obtained from Antrim Shale cores have notable concentrations of hydrocarbons heavier than methane, and have carbon isotopic $\delta^{13}C$ compositions of -50 per mil (Manger and Curtis, 1991), suggesting that the gas was generated thermally within the Antrim Shale.

The Antrim Shale generally is recognized as a fractured reservoir (McGuire and Oliver, 1988). Matrix porosity values determined on core range from 0.5 to 2.2 percent, with corresponding permeability values between 0.8×10^{-4} and 2.8×10^{-4} millidarcies (Young, 1978). Simulation of production from the Stevens No. 1-12 well suggests a fracture spacing of 5 feet (Lang and Oliver, 1991). Interference tests in the Sanilac County project area indicated that the fractures are subvertical and form an interconnected network, effectively linking different wells. The bulk permeability resulting from fractures varied between 2.7 and 88 millidarcies, and varied with reservoir pore pressure (Matthews and others, 1978). In the Otsego County area, fracture orientations determined from core and electrical imaging or Formation MicroScanner® (FMS) logs trended mainly northeast-southwest, with subordinate and local east-west and northwest-southeast trends (Manger and Curtis, 1991). Bulk

Table 6. Gelatinated nitroglycerine shot stimulation data for New Albany Shale wells in Indiana.

County	Sec.-T.-R.	Well Name	IP Before (MCFGPD)	Depth (Feet)	Nitroglycerine	IP After (MCFGPD)	Completion Date
Harrison	6-4S-4E	Harrison No. 1 Miles	NA	850-TD*?	75 lb	112	1941
Harrison	10-4S-4E	Harrison No. 1 Gunther	NA	714-TD?	100 lb	75	1941
Harrison	3-6S-5E	Albertson No. 1 McCauley	Show	250-TD?	4 qt	80	1948
Martin	5-3N-4W	Miles No. 1-A Crane	NA	1,496-1,516	110 qt	2,000	1950
Martin	8-3N-4W	Miles No. 1 Walton	Show	1,492-1,530	105 qt	497	1950
Martin	34-4N-4W	Lyons No. 2 Grafton	Show	1,440-1,475	50 qt	200	1952
Orange	7-1S-2E	Isaacs No. 1 Blevins	Good show	1,055-1,165	990 lb	25	1978

*TD = Total depth

Table 7. Nitrogen-foam fracture stimulation data for New Albany Shale wells in Indiana.

County	Sec.-T.-R.	Well Name	IP Before (MCFGPD)	Depth (Feet)	Nitrogen (MSCF)	IP After (MCFGPD)	Completion Date
Dubois	23-2S-6W	Huntington No. 1 Hopf	Show	2,158-2,195	266	8	1990
Greene	10-7N-7W	Hux Oil Corp. No. 10-2 Richardson	NA	1,780-1,798	150	88	1990
Greene	10-7N-7W	Hux Oil Corp. No. 10-1 Whitaker	NA	1,782-1,812	250	75	1990
Pike	30-1N-6W	Hux Oil Corp. No. 30-1 Whaley & Mattingly	NA	2,145-2,169	150	24	1989
Warrick	17-4S-7W	Eastern Nat. Gas No. 2 Peabody Coal	NA	2,800-3,020	1,200	4,400	1989

permeability resulting from fracturing was found to be 20 millidarcies in the test of the Muskegon Development No. B1-17 well (Lang and Oliver, 1991). The wells with the highest production in Otsego County were associated with small local structural highs, and showed maximum diversity in fracture orientations (Manger and Curtis, 1991).

Ohio Shale

Gas production and potential in the Devonian shales of the Appalachian Basin exist over a broad area including parts of eastern Kentucky, West Virginia, eastern Ohio, western Pennsylvania, and western New York (Zielinski and McIver, 1982; Roen, 1984). Development of gas from the Devonian shale in the Appalachian Basin dates from 1820 (de Witt, 1986). Evaluation efforts supported initially by the DOE and subsequently by GRI have concentrated on the more productive areas of eastern Kentucky, western West Virginia, and adjacent southern Ohio (Yost, 1986; Scheper and Meyers, 1988). In this productive area, by far the largest commercial accumulation of Devonian shale gas is in the Big Sandy Field of eastern Kentucky and adjacent West Virginia.

Production from the Ohio Shale in eastern Kentucky began with the discovery of the Big Sandy Field in 1915 in the Beaver Creek area of Floyd County (Frankie and others, 1986c). Development of the Big Sandy Field reached a peak in the 1940s, with the drilling of as many as 1,400 gas wells in the field area in the 10-year period (Frankie and others, 1986a-c; Moody and others, 1987a-b). In 1951, 97 percent of the gas production in Kentucky came from the Big Sandy Field, with more than 70 percent of that coming from Devonian shale completions (Hunter and Young, 1953). A gradual decline in drilling activity followed until the late 1970s, when rising natural gas prices, followed by the Section 29 production tax incentive, resulted in the drilling of over a thousand new gas wells in the Big Sandy Field area between 1981 and 1990 (Nuttall, 1986, 1987, 1988, 1989b, 1990, 1991).

Kuuskraa and others (1985) estimated a total of 82 TCF of gas-in-place in the Devonian shales of eastern Kentucky, of which between 9 and 23 TCF was estimated to be commercially recoverable. In a review of 3,414 wells drilled in the Big Sandy Field for gas production to the end of 1951, Hunter and Young (1953) showed that the average IP was 336 MCFGPD. This relatively high IP was followed by a rapid decline to a level generally between 50 and 200 MCFGPD, which then declined very gradually over a time period of many years (de Witt, 1986). Water was generally not encountered in the course of gas production from the Ohio Shale.

Devonian shale gas wells in the Appalachian Basin generally require stimulation in order to produce commercial amounts of gas, but some exceptional wells produce effectively on the basis of natural flow. Only 6 percent of the wells drilled in the Big Sandy Field by the end of 1951 were natural producers, having an average IP of 1,050 MCFGPD (Hunter and Young, 1953). The remaining 94 percent of Devonian shale gas wells had an average IP of 60 MCFGPD before stimulation and 290 MCFGPD after stimulation. Stimulation of wells during the period was generally accomplished by shooting the shale section with 80 percent gelatinated nitroglycerine. Kuuskraa and others (1985) discussed the incremental benefits to be obtained by replacing borehole shot stimulation with hydraulic fracturing. Results of more recent foamed-nitrogen fracture treatments were summarized by Lancaster (1990).

The gas from Devonian shales in the Appalachian Basin is variable in composition, but generally contains hydrocarbons heavier than methane. The ratio of methane (C_1) to the sum of hydrocarbons from methane through pentane (C_1 to C_5) varies from 0.60 to 0.99 in gas produced from Devonian shale wells in the Appalachian Basin (Claypool and others, 1978). Analyses of headspace gas from Devonian shale cores in the Appalachian Basin resulted in $C_1/(C_1$ to $C_5)$ ratios between 0.69 and 0.89 (Claypool and Threlkeld, 1978; Snyder and others, 1978; Zielinski, 1978). Carbon dioxide concentrations in natural gas produced from Devonian shale wells in the Appalachian Basin varied between 0.1 and 0.4 percent (Claypool and others, 1978), whereas the range for headspace gas was 0.6 to 3.1 percent (Claypool and Threlkeld, 1978; Snyder and others, 1978; Zielinski and others, 1978). Analyses of headspace gas obtained from Devonian shale samples in the Appalachian Basin show isotopic $\delta^{13}C$ values ranging from -20.5 to -54.9 per mil (Zielinski and McIver, 1982). Values reported by Claypool and others (1978) for analyses of gas produced from Devonian shale gas wells range from -41.9 to -54.0 per mil. These values are in the range of thermogenic gas (Floodgate and Judd, 1992).

The Devonian shales of the Appalachian Basin consist of assemblages of interbedded dark-gray and green-gray shales of variable stratigraphic nomenclature (Hamilton-Smith, 1988). High-precision core analysis of Devonian shales reported by Soeder (1986) indicated that matrix porosity values ranged from less than 0.01 percent to 9.3 percent, with corresponding matrix permeability values from less than 0.02×10^{-5} to 0.02 millidarcies. Kuuskraa and others (1985) reported matrix porosity values between 0.4 and 4.6 percent for Devonian shales of eastern Kentucky, and corresponding permeability values ranged from less than 0.01×10^{-10} to 0.04 millidarcies.

Effective production from the Devonian shales of the Appalachian Basin is due to the presence of natural fractures, which have been documented by numerous core and FMS logs studies (Kulander and others, 1977; Lowry and others, 1989; Guidry and others, 1991). In addition to the presence of fractures, a key feature of Devonian shale gas reservoirs is their capacity for storage of gas by adsorption onto kerogen and clay surfaces (Schettler and Parmely, 1987b, 1990; Schettler and others, 1988).

Comparison of the New Albany Shale to the Antrim and Ohio Shales

Gas production from the New Albany Shale of the Illinois Basin has some general similarities to gas production from the Antrim Shale of the Michigan Basin and the Ohio Shale of the Appalachian Basin. Estimated gas-in-place of the Devonian shales of the Michigan Basin and the Appalachian Basin is comparable to the estimated gas-in-place for the New Albany Shale of the Illinois Basin (Oliver and others, 1989) (fig. 11). However, drilling activity directed at Devonian shale gas to date has been significantly less in the Illinois Basin than in either the Michigan or the Appalachian Basin.

The fractured and gas-absorptive character of the reservoir and the thermal origin of the gas is similar in the Michigan, Appalachian, and Illinois Basins. The general gas production rates from the three shale units are grossly similar. There appears to be a small fraction of wells (less than 10 percent) producing from the Ohio Shale that do so at significantly higher rates (greater than 1,000 MCFGPD) than wells producing from either the Antrim Shale or the New Albany Shale. The average IP from gas wells in the Antrim Shale may be somewhat lower than the average rate from wells in the New Albany Shale, which in turn seems to be slightly less than the average IP from Ohio Shale gas wells. The benefits and limits of fracture stimulation of gas wells in the three shale units appear to be generally similar.

Differences include the pervasive production of water in association with gas from the Antrim Shale, as contrasted with the virtual absence of water production from Ohio Shale gas wells. Water has been encountered in the New Albany Shale gas fields in southern Indiana and the immediately adjacent areas of Kentucky; however, gas production from the New Albany Shale south of the Rough Creek Fault System in Kentucky is not accompanied by water. Where water is encountered in conjunction with New Albany Shale gas, it commonly originates from a distinct zone either low in the New Albany Shale section or in the underlying permeable carbonates and is not pervasive throughout the entire fracture system. Detailed data concerning water production from the New Albany Shale, including flow rates, salinities, and disposal practices, are not available.

Another distinct difference in gas production from the three shale units concerns the concentration of carbon dioxide in the produced gas. A relatively high carbon dioxide concentration in Antrim Shale gas, in conjunction with pervasive water production, results in a practical problem of corrosion of downhole pumps and tubing required to lift the water and support gas production. In the Ohio Shale, carbon dioxide concentrations are relatively low, and there is a virtual absence of associated water production, so that corrosion problems are insignificant. In the New Albany Shale, carbon dioxide concentrations in produced gas appear to be intermediate between those of the Ohio Shale and the Antrim. Where water associated with New Albany Shale gas production is negligible, as is the case in the southern half of the Illinois Basin, the carbon dioxide concentration should result in very little corrosion. Where water production frequently accompanies gas production from the New Albany Shale, as in most of the Indiana fields, the combination of carbon dioxide and water may result in problems similar to those associated with production from the Antrim Shale.

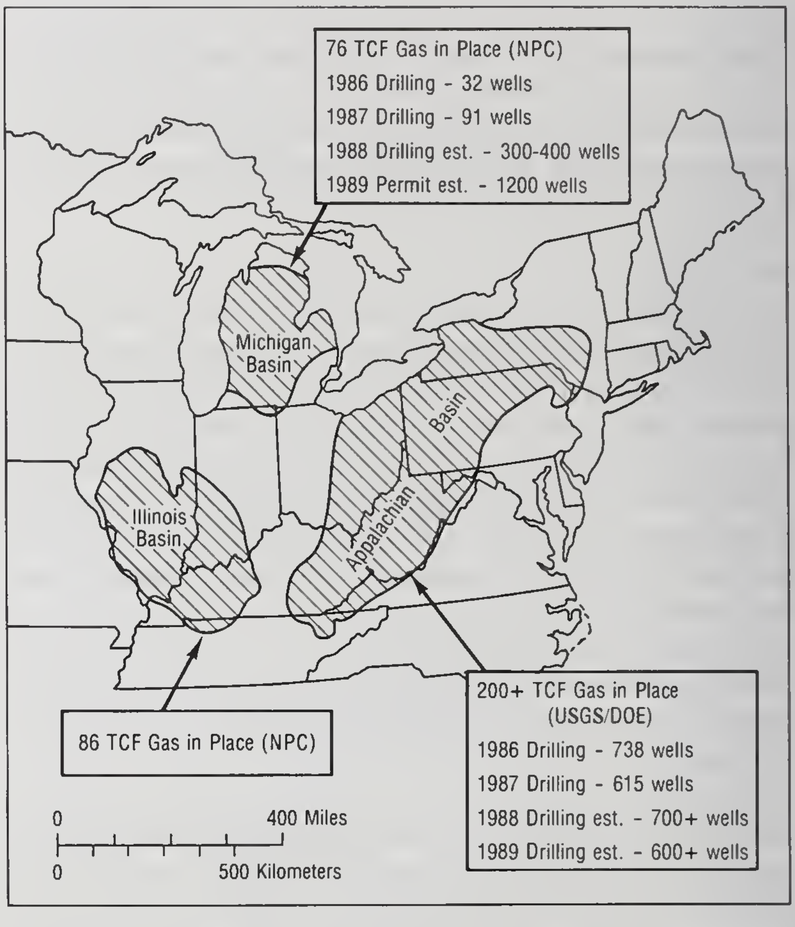

76 TCF Gas in Place (NPC)
1986 Drilling - 32 wells
1987 Drilling - 91 wells
1988 Drilling est. - 300-400 wells
1989 Permit est. - 1200 wells
Michigan Basin
Appalachian Basin
Illinois Basin
86 TCF Gas in Place (NPC)
200+ TCF Gas in Place (USGS/DOE)
1986 Drilling - 738 wells
1987 Drilling - 615 wells
1988 Drilling est. - 700+ wells
1989 Drilling est. - 600+ wells
0
400 Miles
0
500 Kilometers

Figure 11. Devonian shale resources and activity in the Appalachian, Illinois, and Michigan Basins. NPC = National Petroleum Council; USGS = U.S. Geological Survey; DOE = U.S. Department of Energy. Modified from Oliver and others (1989).

MINERALOGY AND GEOCHEMISTRY

By Joyce K. Frost and Nelson R. Shaffer

Introduction

Details of the mineralogy and geochemistry of a black shale are relevant to evaluating its source rock potential. The organic carbon content is the single most important variable with respect to oil and gas potential of a shale. Carbonates bear on the porosity of the shale and the clay minerals reflect the temperature to which it has been subjected. A knowledge of the mineralogy is useful for understanding the geophysical data. Some trace elements are known to present problems (for example, catalyst poisoning) in shale-retorting processes. Therefore, a summary is presented here of the mineralogical and geochemical data on the New Albany Shale in the Illinois Basin.

Organic Carbon Content

The amount of organic carbon in the New Albany Shale is quite variable, both stratigraphically and areally, ranging from less than 0.1 to more than 20 weight percent. Organic carbon content as high as 25 percent has been reported in a few thin organic-rich beds in Clark County, Indiana (Leininger, 1981).

Stevenson and Dickerson (1969) reported on the organic carbon content of about 350 samples from the lower 50 feet of the New Albany in Illinois. The samples averaged over 4 percent organic carbon, and ranged from over 9 percent in central Illinois to less than 1 percent along the western and southwestern margin of the Illinois Basin along the Mississippi River. In more recent studies, the organic carbon content of each shale member has been measured (table 8). The uppermost members, the Saverton and Hannibal shales, averaged 1 to 2 percent in samples analyzed from Illinois (Frost, 1980). Low values (less than 1 to 2 percent) were also measured in the Selmier Member in southeastern Indiana (Leininger, 1981), but some beds therein contain as much as 7 percent organic carbon (Leininger, 1981; Hasenmueller and Leininger, 1987). The Selmier and Sweetland Creek shales averaged 2.5 to 6.5 percent organic carbon in samples from Illinois (Frost, 1980).

The Grassy Creek shale has moderately low organic carbon content (2 to 5 percent) in the extreme northwestern part of the Illinois Basin, but elsewhere in Illinois it averages 5 to 9 percent organic carbon. The equivalent stratum in Indiana is consistently organic-rich. The average percentage of organic carbon in samples of the Clegg Creek Member from ten cores in southeastern Indiana ranges from 10.4 to 13.7 percent (Hasenmueller and Leininger, 1987). Organic carbon averages 5.5 percent in the Morgan Trail Member and ranges from 1 to 11 percent in the Camp Run Member in southeastern Indiana.

Thiessen (1925) reported concentrations of organic matter between 13 and 30 weight percent from the New Albany Shale in western Kentucky. However, because his measurements were based on weight loss on burning, they overestimate organic carbon content. Frost and others (1985) reported a more reliable range of 1.6 to 14 percent organic carbon for the shale members from samples in a core from Christian County. Robl and others (1984) reported that the organic carbon content in 11 near-outcrop cores in west-central Kentucky varies stratigraphically, having values of 9.3 to 13 percent for samples from the Clegg Creek equivalent of the Grassy Creek, 7 to 8.8 percent for samples from the Camp Run equivalent of the Grassy Creek, 6.1 to 11.8 percent for samples from the Morgan Trail equivalent of the Grassy Creek, and 8.1 to 9.9 percent for samples from the Blocher Member. In cores from southeastern Indiana, the Blocher contains 6.8 to 9.4 percent organic carbon (Hasenmueller and Leininger, 1987), and in Illinois it averages 4 to 9 percent organic carbon (Frost, 1980).

Mineralogy

The mineral portion of the shale is composed of quartz, clay minerals, muscovite mica, minor amounts of potassium feldspar and plagioclase, and carbonates–predominantly dolomite with minor amounts of calcite, pyrite, and marcasite. The mineralogic composition relative to shale stratigraphy is illustrated by data for two cores from Indiana (fig. 12). Harvey and others (1980) observed minor quantities of the heavy minerals rutile, zircon, glauconite, amphibole, and pyroxene in samples from Illinois. In samples from Indiana, Shaffer and Chen (1981) noted the minor detrital components sericite, feldspars, tourmaline, and glauconite, and the authigenic trace minerals carbonate-fluorapatite, apatite, siderite, rhodochrosite, sphalerite, chalcopyrite, galena/clausthalite, barite, and chalcedony. A variety of sulfates, such as gypsum, melanterite, and jarosite, occur on weathered surfaces (Shaffer and Branam, 1991).

The clay fraction consists of only a few types of minerals, principally illite, chlorite, mixed-layer, and expandable clays (Harvey and others, 1980). Illite is the most abundant, and only the 2M polytype has been detected. The proportion of illite in all samples from the Grassy Creek and the Selmier and Sweetland Creek increases from the northern part of Illinois to the southeastern part of Illinois. Variation in the crystallinity of the illite has been observed, but it could not be related to other parameters, such as depth of burial or temperature of lithification. The expandable clay minerals include an illite-smectite type usually at the level of 1 to 2 parts expandable clay per 10 parts and rarely more than 3 parts per 10. Chlorite occurs widely, although it is not generally present in the Blocher Shale Member in Illinois nor in the shales within the Fluorspar Area Fault Complex of southeastern Illinois (Hardin and Pope Counties). The shales overlying the Blocher generally contain 20 to 30 percent chlorite in the clay fraction, but

Table 8. Percentage of organic carbon by weight averaged by lithologic unit in samples from Devonian and Mississippian cores in Illinois, Indiana, and western Kentucky. When the number of samples (n) averaged is 2 or greater, the standard deviation (1σ) is given. Data are from Frost (1980), Hasenmueller and Leininger (1987), and unpublished Indiana Geological Survey analyses.

		ILLINOIS				KENTUCKY		INDIANA		
Rock Unit		Henderson Co. 04IL*	Tazewell Co. 06IL	Effingham Co. 02IL	Wayne Co. 13IL	Christian Co. 01KY	Bullitt Co. 02KY	Sullivan Co. Phegley	Marion Co. SDH No. 273	Clark Co. SDH No. 290
Chouteau Ls. (Rockford Ls.)				0.36 (1)						0.20 (1)
New Albany Shale	Jacobs Chapel Bed								0.22 (1)	0.98±0.31 (2)
	Henryville Bed								15.4 (1)	23.1±1.8 (6)
	Falling Run Bed									1.4 (1)
	Hannibal and Saverton Mbrs.	1.1±0.7 (14)	1.1±0.9 (19)	2.0±0.4 (2)	0.96 (1)					
	Ellsworth Mbr.								0.52±0.38 (2)	
	Grassy Creek (Sh.) Mbr.	2.8±0.7 (4)	6.9±2.1 (15)	7.2±2.1 (6)	6.8±1.4 (14)	7.6±4.6 (5)				
	Clegg Creek Mbr.						14.8±0.8 (2)†	9.5±2.4 (9)	7.6±2.3 (14)§	11.6±3.6 (37)
	Camp Run Mbr.						5.5±0.8 (4)†	5.3±2.2 (11)‡		5.7±3.6 (32)
	Morgan Trail Mbr.						7.4±1.9 (2)†			5.7±1.8 (33)
	Sweetland Creek Sh. Mbr.	1.7±1.5 (14)	2.6±1.2 (6)	4.3±1.8 (3)						
	Selmier (Sh.) Mbr.				3.5±1.4 (6)	6.4±3.3 (9)		4.1±2.6 (8)	3.2±3.4 (10)	
	Blocher (Sh.) Mbr.				3.7±0.3 (3)	6.2±1.0 (4)	9.0 (1)	5.3±0.9 (7)	6.1±3.5 (8)	8.5±1.7 (9)
Cedar Valley Ls.		0.57±0.25 (2)	1.5 (1)							
Lingle Ls. (North Vernon Ls.)			0.34 (1)							0.68±0.12 (2)

*Core Designation	State	County	Location	Well Name
04IL	Illinois	Henderson	32-8N-4W	Northern Illinois Gas No. 1 RAR
06IL	Illinois	Tazewell	8-23N-2W	Northern Illinois Gas No. 1 MAK
02IL	Illinois	Effingham	31-9N-4E	Tri Star Prod. No 1-D Lancaster
13IL	Illinois	Wayne	17-3S-8E	Jenkins No. 1 Simpson
01KY	Kentucky	Christian	12-G-25	Orbit No. 1 Clark
02KY	Kentucky	Bullitt	3-S-46	Norm No. 1 Knievim
Phegley (011N)	Indiana	Sullivan	14-6N-10W	Energy Resources Indiana No. 1 Phegley Farms
SDH No. 273	Indiana	Marion	27-15N-2E	Indianapolis Intl. Airport
SDH No. 290	Indiana	Clark	283 CMG-2N-7E	Clark County State Forest

†In Kentucky this stratigraphic interval is equivalent to the Grassy Creek Member.

‡Percentage of organic carbon averaged for the Camp Run and Morgan Trail Members.

§Percentage of organic carbon averaged for the Clegg Creek, Camp Run, and Morgan Trail Members.

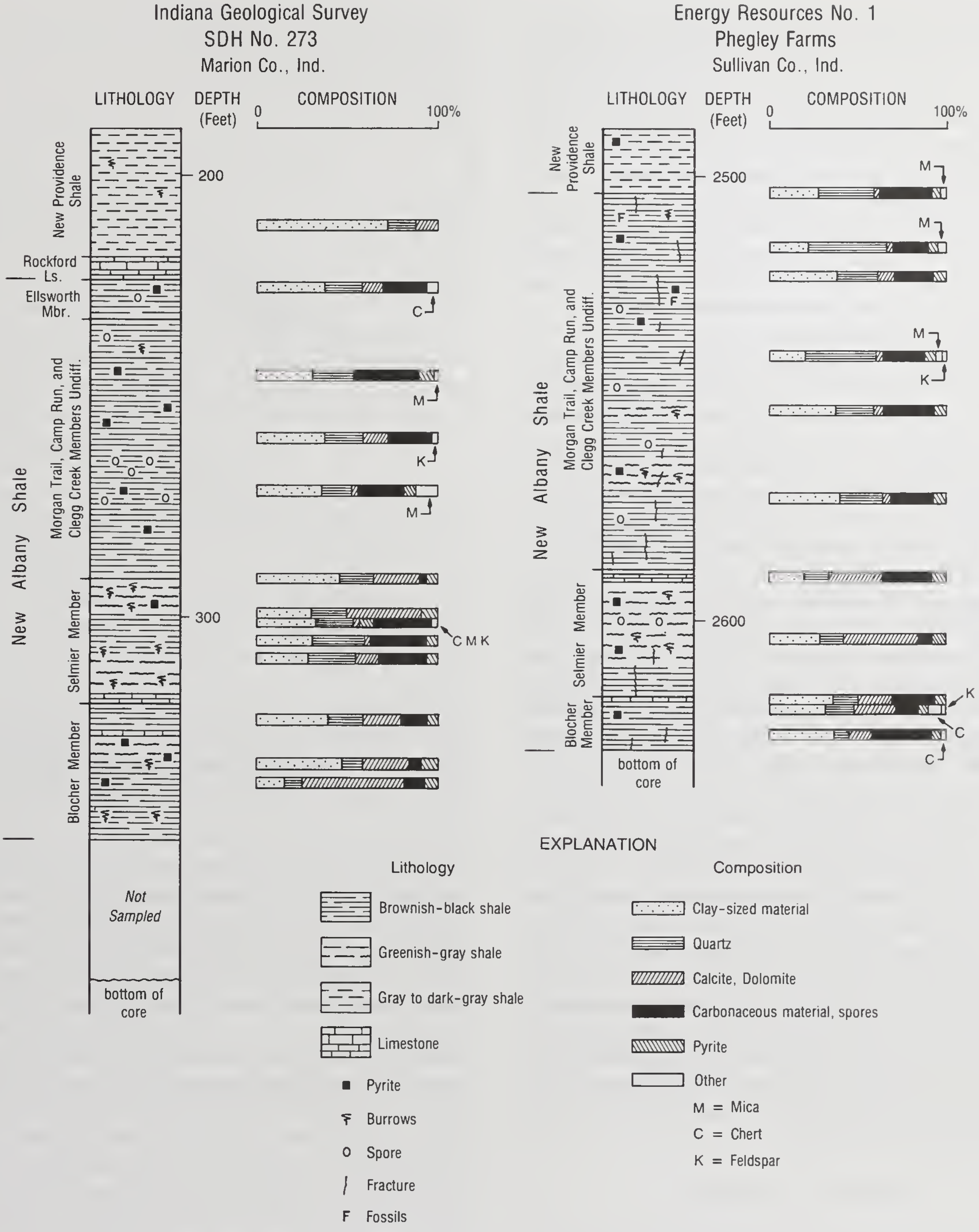


Figure 12. Mineralogical composition of the New Albany Shale in cores from Indiana Geological Survey SDH No. 273 in Marion County, Indiana, and Energy Resources of Indiana No. 1 Phegley Farms Inc., Sullivan County, Indiana. Modified from Shaffer and Chen (1981).

in southeastern Illinois these shales more commonly contain 10 to 20 percent chlorite. Shaffer and Chen (1981) report an illite to chlorite ratio of 6.5 to 3.5 for the New Albany Shale in Indiana.

Quartz is abundant and occurs mostly as detrital grains ranging in size from less than 2 μm to about 90 μm in diameter (Harvey and others, 1980). Flakes of muscovite mica are commonly visible in thin sections. Both potassium and sodium feldspars are present. Plagioclase is particularly abundant in the Hicks Dome area of Hardin County, Illinois, and samples from the Rector & Stone No. 1 Missouri (MO) Portland Cement core (11IL) have 3.1 percent mean concentration of sodium, as Na_2O, compared with 0.5 percent mean concentration of Na_2O measured in shale from other localities in Illinois.

X-ray diffraction analyses indicate that both dolomite and calcite are present in all of the New Albany Shale members. Carbonate concentrations are greatest in the Blocher. Twenty-four samples from the Blocher in Illinois had a carbonate carbon content equivalent to 7.4 to 46.8 percent dolomite plus calcite (Frost and others, 1985). Calculations based on the calcium and magnesium contents of the samples indicate the dolomite ranges from 17 to 100 percent of the carbonate mineral fraction. On average, the concentration of dolomite is greatest in the lower part of the formation. The dolomite occurs mostly as euhedral silt-sized rhombs set in a matrix of clay minerals; the rhombs are interpreted as syngenetic. Robl and others (1984) reported an average of 11.0 percent mineral carbon, as carbon dioxide, in the Blocher from 11 cores in west-central Kentucky. The carbon dioxide content in the Blocher in three cores from Indiana (Phegley, SDH[8] No. 273, and SDH No. 290) averages 12.8, 11.1, and 9.8 percent, respectively.

Essentially all of the sulfur in freshly drilled New Albany Shale cores is pyritic; only trace amounts of marcasite are present. Pyrite occurs in several different forms, including silt-sized framboids, nodules of varying size, lenticular forms along bedding planes, burrow fillings, and isolated euhedral crystals. Pyritized burrows and scattered pyrite nodules are present in the grayish-green, olive-green, and gray bioturbated mudstones of the Hannibal and Saverton and in indistinctly bedded shales of the Sweetland Creek, Selmier, and the lower half of the Saverton. Very fine, even, and closely spaced pyritic laminae and numerous small pyrite lenses are present in the brownish-black to grayish-black, finely laminated shales of the Grassy Creek, Clegg Creek, Morgan Trail, and Blocher.

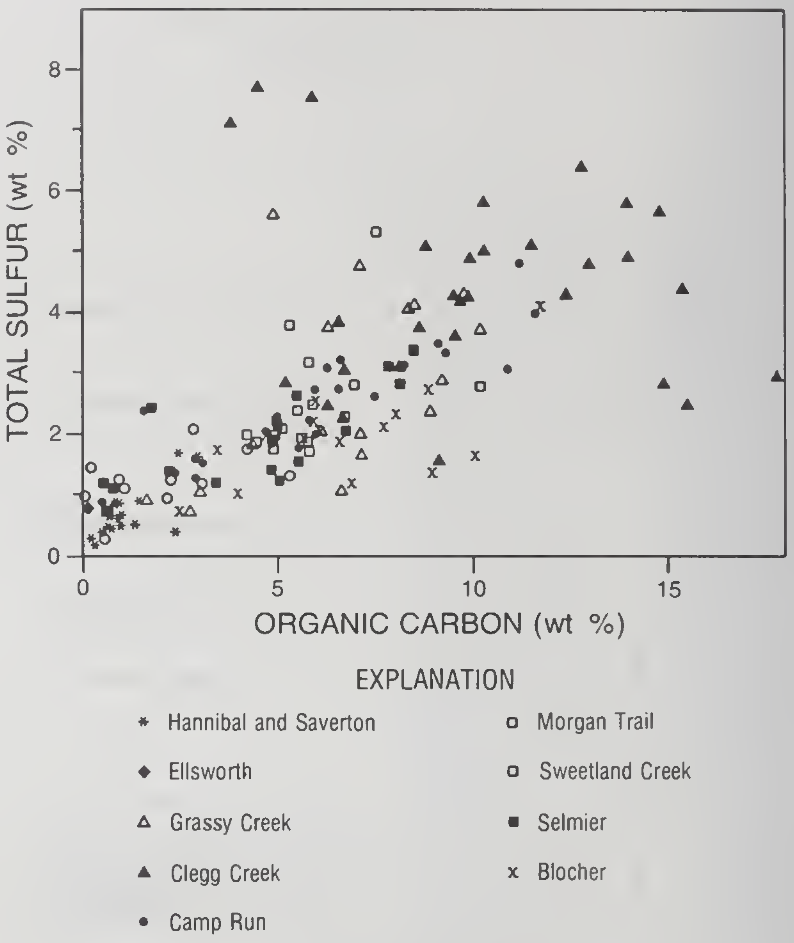


Figure 13. Relationship between total sulfur and organic carbon in samples of the New Albany Shale from the Illinois Basin. Data are from samples of shale members (beds omitted) in the cores listed in table 8.

Inorganic Geochemistry

In general, there is a direct relationship between the concentrations of total sulfur or pyritic sulfur and organic carbon for most of the New Albany Shale samples (fig. 13). Thus, pyrite content, as calculated from total sulfur concentration, is relatively low in the Saverton and Hannibal Shale Members in Illinois and generally highest in beds equivalent to the Grassy Creek, Clegg Creek, and Camp Run of southeastern Illinois, Indiana, and Kentucky. Samples of the Saverton and Hannibal from Illinois average 1.4 percent pyrite, and samples of Selmier and Sweetland Creek average 3.2 percent pyrite. In samples of the Clegg Creek Member from ten shallow cores in southeastern Indiana in which organic carbon ranged from 10.4 to 13.7 percent, average sulfur ranged from 4.2 to 5.5 percent, equivalent to 7.8 to 10.3 percent pyrite (Hasenmueller and Leininger, 1987). The top of the Clegg Creek and the very organic-rich Henryville Bed in Indiana, however, have a very low ratio of sulfur to organic carbon content; they average about 5 percent pyrite (Hasenmueller and Leininger, 1987). The Grassy Creek in Illinois averages 4.7 percent pyrite and several samples contain 6 to 10 percent pyrite. Robl and others (1984) noted that the carbonate-rich Blocher in a core from Madison County, Kentucky, was organic-rich but comparatively lower in sulfur than the other New Albany strata. Frost and others (1985) reported an average of 3.6 percent pyrite in Blocher samples that average 4 to slightly more than 9 percent organic carbon. In ten cores from southeastern Indiana, the Blocher contains 6.8 to 9.4 percent organic carbon and 1.7 to 2.4 percent sulfur, equivalent to 3.2 to 4.5 percent pyrite (Hasenmueller and Leininger, 1987). Shale layers with high pyrite content are likely to be the best gas producers because they have more organic carbon, and iron sulfide has a potential catalytic effect on the transformation of organic matter to oil and gas.

---

[8] SDH = Indiana Geological Survey drill hole.

Except for the carbonates and the pyrite, the inorganic portion of the New Albany is relatively uniform in composition. The Falling Run Bed, the phosphate nodule layer, is distinctive. Most other New Albany Shale strata are low in phosphate (less than 0.1 percent phosphorus as P_2O_5), although Frost and others (1985) reported that a few samples contained 0.5 to 4 percent phosphorus, as P_2O_5, and are enriched in fluorine and rare earth elements. Abundances of these elements are directly related to the phosphatic fossil debris and sedimentary nodules that occur sporadically in the section, most commonly in the Grassy Creek and Clegg Creek strata, and less commonly in the Blocher.

Trace metal enrichment in the New Albany is typical of that in black shales. Frost and others (1985) reported enrichment in the trace elements uranium (U), molybdenum (Mo), arsenic (As), antimony (Sb), selenium (Se), copper (Cu), nickel (Ni), and vanadium (V). The order of enrichment in members of the New Albany Shale in Illinois is, from least to greatest, Saverton and Hannibal, Selmier and Sweetland Creek, Blocher, and Grassy Creek. There is a slight enrichment in cobalt (Co) and lead (Pb), and a sporadic enrichment in zinc (Zn) and silver (Ag) in organic-rich samples from the deep basin in southeastern Illinois. Concentrations of Cu, Ni, and V are highest in the Blocher. In the deep part of the basin in Illinois, the upper part of the Grassy Creek is enriched in Se, Sb, V, Zn, and Ag; however, the concentration of pyrite is small due to the lack of detrital sediment that was the principal source of iron. Average ranges for the concentrations of the elements were as follows: U, 3 to 39 parts per million (ppm); Mo, less than 3 to 96 ppm; As, 4 to 45 ppm; Sb, 0.5 to 5 ppm; Se, less than 1 to 14 ppm; Cu, 20 to 170 ppm; Ni, 25 to 140 ppm; V, 80 to 350 ppm; Co, 9 to 30 ppm; Pb, 3 to 63 ppm; Zn, 25 to 450 ppm; and Ag, less 0.1 to 0.8 ppm. Maximum concentrations were about twice these values.

Robl and Koppenaal (1982) found enrichment in Mo, Pb, V, Zn, and U in samples from the upper 20 to 30 feet of the New Albany at outcrops in Bullitt, Nelson, and Russell Counties, Kentucky. Markowitz (1979) reported metal enrichment in samples from three shale outcrops in south-central Kentucky and one outcrop near Louisville, Kentucky. Leung and Sanders (1973) analyzed samples of New Albany Shale from 25 counties in Kentucky. They reported V ranging from 100 to 450 ppm, 220 to 250 ppm in most samples; chromium (Cr) ranging from 45 to 130 ppm, 45 to 60 ppm in most samples; and Co ranging from 10 to 70 ppm, 15 to 20 ppm in most samples. Crouse (1925) determined precious metal values of 0 to 0.225 oz/ton for Ag and 0 to 0.02 oz/ton for gold (Au) in New Albany samples from Kentucky.

Summaries describing the inorganic geochemistry of the New Albany Shale in Indiana can be found in Hasenmueller and Leininger (1987), Shaffer and others (1983, 1984), Hasenmueller and others (1983b), and Leininger (1981). Special attention to phosphates was paid by Shaffer and others (1988). Metal enrichment is greatest towards the top of the Clegg Creek Member. In cores from southeastern Indiana, Lechler and others (1979) found enrichment in Ag, cadmium (Cd), Cr, Cu, Mo, Ni, Pb, V, and Zn. The thin Falling Run, Underwood, Henryville, and Jacobs Chapel Beds at the very top of the Clegg Creek are distinctive. The Falling Run Bed, the phosphate nodule layer, has high concentrations of phosphorus, yttrium (Y), U, and associated elements (Lechler and others, 1979; Shaffer and others, 1988). The Henryville Bed contains intervals having organic carbon content greater than 20 weight percent and metal enrichment (as much as 5,500 ppm V and 6,500 ppm Zn) an order of magnitude greater than that reported in other New Albany strata (Ripley and others, 1990). Desborough (1992) also reported as much as 1,200 ppm V and 1,600 ppm Zn in the Henryville Bed in a core from the Rose Mine, Hardin County, Illinois.

Leventhal and Kepferle (1982) reported two areas, one in south-central Kentucky, where the New Albany is exposed along the Cincinnati Arch, and a second near Louisville, Kentucky, and extending northward into Floyd and Clark Counties, Indiana, where the New Albany Shale contains an average of about 60 ppm U. They also reported that the New Albany Shale in these two areas is enriched in pyrite, Mo (90 ppm), Ni (150 ppm), As (60 ppm), V (300 ppm), and mercury (Hg), and some samples are enriched in Cu, Pb, and Zn. Samples of phosphate nodules from the Falling Run Bed contained concentrations of U as great as 278 ppm (Leventhal and Kepferle, 1982).

SOURCE ROCK POTENTIAL

By John B. Comer, Terence Hamilton-Smith, and Wayne T. Frankie

Introduction

Nearly all of the New Albany Shale strata qualify as hydrocarbon source rocks on the basis of their organic carbon content. For example, Barrows and others (1980) stated that 86 percent of 371 Illinois Basin samples analyzed by Frost (1980) contained greater than 1.0 weight percent organic carbon, and 97 percent exceeded the critical 0.5 percent organic carbon level. Organic carbon concentrations are described in detail in the preceding chapter, "Mineralogy and Geochemistry." The highest organic carbon concentrations, varying mostly between 6 and 15 weight percent, are in the basal Blocher (Shale) Member of Kentucky, Indiana, and southeastern Illinois and in the upper part of the Grassy Creek (Shale) Member and correlative strata in the Camp Run and Clegg Creek Members in southeastern Illinois, Indiana, and western Kentucky. Organic carbon values are moderately high (2 to 6 percent) in the Sweetland Creek Shale and Grassy Creek (Shale) Members in the west, and also in some beds in the Sweetland Creek Shale and Selmier (Shale) Members of Indiana and central and southeastern Illinois. Organic carbon concentrations of less than one percent are common in the Selmier Member in some counties in southeastern Indiana, in the Saverton and Hannibal Shale Members in the northwestern part of the Illinois Basin, and in parts of the Ellsworth Member in Indiana.

Organic Matter Type

Kerogen concentrates from samples of New Albany Shale usually contain 90 to 95 percent amorphous organic matter, and the macerals vitrinite, liptinite, and inertinite account for only 5 to 10 percent of the organic fraction (Barrows and others, 1980). Pyrolysis analysis by Rock-Eval® of 159 samples indicates that the organic matter in most New Albany Shale samples consists predominantly of Type II kerogen (Chou and others, 1991) (fig. 14). Amorphous, Type II kerogen is known to have substantial oil- and gas-generating potential (Hunt, 1979; Tissot and Welte, 1984). Correlation by gas chromatography of crude oil in reservoirs and bitumen extracted from the rock samples has led to the conclusion that the New Albany is the major source of oil in Pennsylvanian, Mississippian, Devonian, and Silurian reservoirs in the Illinois Basin (Chou and others, 1991; Hatch and others, 1991).

Hutton (1991) pointed out that the classification of kerogen into Types I, II, and III based on the results of bulk chemical analyses plotted on a modified van Krevelen diagram (fig. 14) represents the average chemical composition of the maceral assemblage, rather than characteristics of a single kerogen type. With specific reference to the Ohio Shale, the equivalent of the New Albany Shale in the Appalachian Basin, he suggested that the Type II bulk chemical composition may result from a mixture of Type I tasmanitid telalginite and amorphous bituminite of Type III affinities. Robl and others (1991) suggested that amorphous bituminite in the New Albany Shale may be derived in part from bacterial degeneration of humic vitrinite. If humic kerogen composes a large part of the organic matter in the New Albany Shale, then a significant degree of gas generation may have been associated with the generation of oil.

The type of organic matter in the New Albany Shale is related to lithofacies and was controlled by environmental conditions that existed in and around the basin during deposition (Barrows and Cluff, 1984). In general, individual lithofacies and the type of organic matter contained in each can be predicted from petrologic and geophysical log data. The black shales typically have parallel laminae, incorporate more than 2.5 weight percent organic carbon, are the most radioactive, and contain predominantly amorphous, Type II kerogen (Barrows and Cluff, 1984). The gray shales commonly exhibit bioturbated fabric, have organic carbon concentrations of 1 to 2 weight percent, are moderately radioactive, and contain predominantly humic, Type III kerogen, composed of vitrinite and inertinite (Barrows and Cluff, 1984). High organic carbon content generally correlates directly with high radioactivity on the gamma-ray logs and high concentrations of natural gas released from cores (Lineback, 1980; Meinshein, 1981; Cluff and Dickerson, 1982). Also, the uranium (U) content shows a significant positive correlation with organic carbon (Frost and others, 1985). Thus, the most radioactive black shales typically are the principal hydrocarbon source beds in the formation, whereas the gray shales have much less hydrocarbon source potential.

The Blocher (Shale) Member appears to be an exception to the above rule in that it contains strata with high organic carbon concentrations but exhibits much lower gamma-ray responses compared with the other organic-rich units (Hasenmueller and Leininger, 1987). Although there is a significant positive correlation between U and organic carbon for samples from the Blocher, the confidence level is lower than that for the other New Albany Shale members (Frost and others, 1985). The low gamma-ray response is caused by the generally lower uranium concentrations and lower ratios of uranium to organic carbon in the Blocher compared with the other members (Frost and others, 1985). Thus, some strata, especially those in the Blocher, are only moderately radioactive but contain high concentrations of organic carbon and therefore have significant hydrocarbon source potential.

Thermal Maturity

Quality of Data

The average $\overline{R}_o$ values presented in this report (appendix C, pl. 7) are the most comprehensive suite of thermal-maturity data for the New Albany Shale in the Illinois Basin. However, caution with the interpretation and application of these data is urged

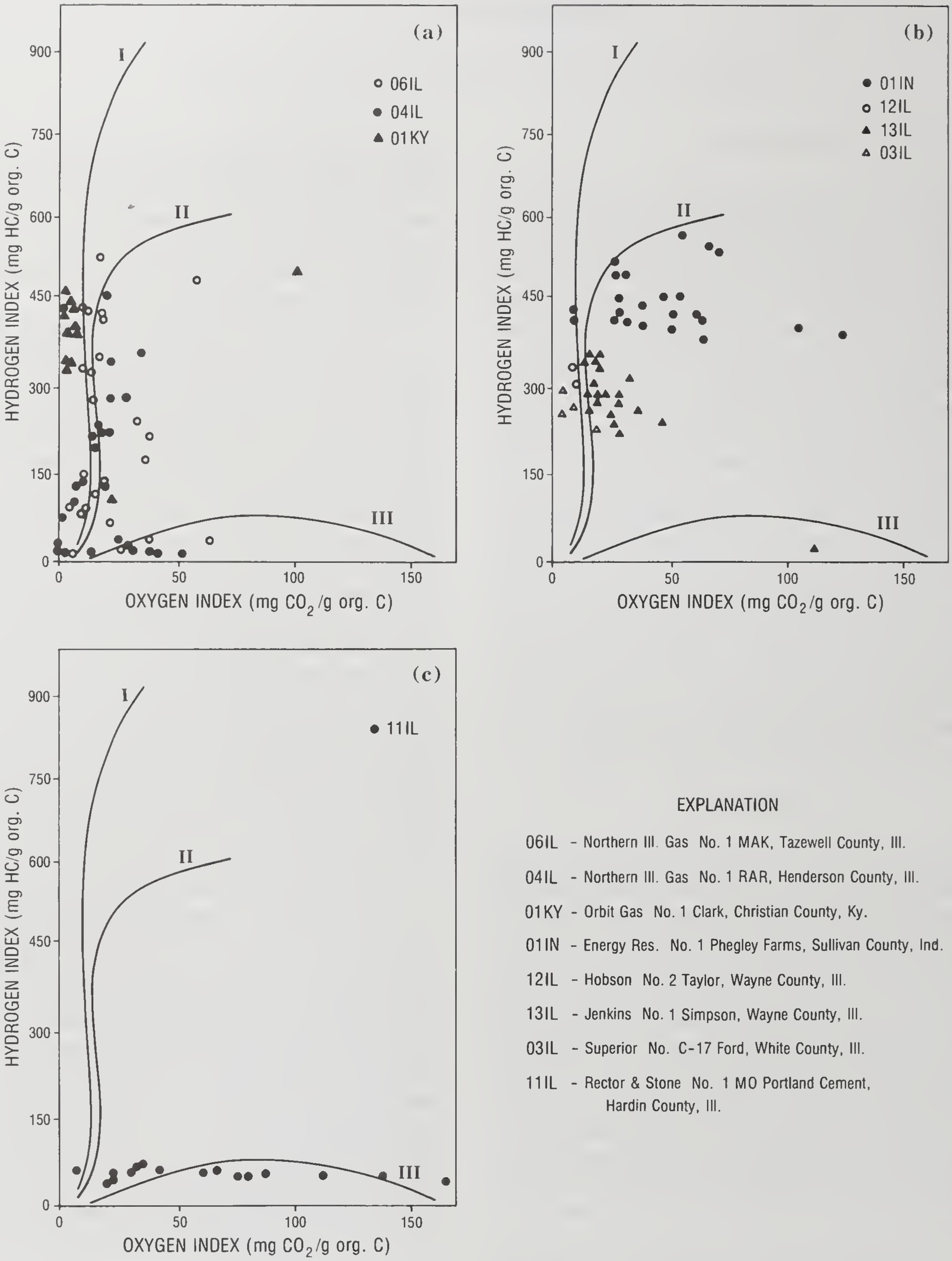


Figure 14. Modified van Krevelen diagrams showing Rock-Eval® data for core samples of the New Albany Shale. Samples from core 11IL are high-maturity samples that have been oxidized; hence they may contain little or no Type III kerogen (see discussion in text). From Chou and others (1991).

because of the difficulties inherent in sample preparation and maceral identification and the scarcity of independent maturity data from the same samples for comparison. The method of preparation, which used hydrochloric and hydrofluoric acids to concentrate the organic fraction for petrographic analysis, is known to destroy the structure and reduce the fluorescence of some samples (Buiskool Toxopeus, 1983), and recoveries sometimes are small and unrepresentative (Price and Barker, 1985). For prepared samples of the New Albany Shale, maceral identification generally was difficult because particles were commonly the size of fine silt or smaller and were widely dispersed (Barrows and others, 1980). Consequently, the diagnostic morphologic and reflectance characteristics, previously established and standardized from the petrographic studies of coals, were not always visible under the microscope, and a comparison between two or more macerals in the same field of view was often impossible (Barrows and others, 1980). Because of these problems, small liptinite fragments may have been mistakenly identified as vitrinite in some samples and fine-grained semifusinite may have been counted as vitrinite in others, resulting in $\overline{R}_o$ measurements that are respectively lower or higher than those exclusively for vitrinite (Barrows and others, 1980).

During the petrographic analyses (Barrows and others, 1980), no attempt was made to distinguish the different syngenetic types of vitrinite that are known to have significantly different reflectance values nor to measure the reflectance of telocollinite on which the coal rank scale is based. It is possible that the vitrinite in the New Albany is altered or a different type than that present in coals, so that direct application of the conventional thermal-maturity scales used to determine coal rank and hydrocarbon generation is inappropriate. Furthermore, the reflectance of vitrinite in the New Albany Shale may be suppressed as it is in other amorphous-rich, oil-prone source beds (Hutton and Cook, 1980; Price and Barker, 1985). Measurement of the low-reflectance type of vitrinite (for example, the vitrinite-2 of Buiskool Toxopeus [1983]) or vitrinite in an alginite matrix typically may yield suppressed reflectance values and widely scattered data. Unfortunately, the magnitude of suppression may vary from grain to grain and from sample to sample, and it cannot be estimated accurately (Hutton and Cook, 1980; Buiskool Toxopeus, 1983; Price and Barker, 1985).

Although precise comparison of $\overline{R}_o$ data in this report with the classical rank scale used by coal petrologists and the hydrocarbon generation scales developed by petroleum geochemists may not be valid, these data (appendix C, pl. 7) are consistent with published studies by Barrows and Cluff (1984), Chou and others (1991), and Hatch and others (1991) concluding that the New Albany Shale is a mature hydrocarbon source rock. Despite the inherent problems associated with measuring the reflectance of vitrinite in samples from the New Albany Shale, the available data confirm that the variations in average $\overline{R}_o$ are related to the present depth of burial and to prominent structural features (pl. 7).

Interpretation

Average $\overline{R}_o$ values for the 223 wells reported in this study range from 0.44 to 1.50 percent (appendix C, pl. 7). The highest average value is at Hicks Dome in Hardin County, southeastern Illinois, and the lowest average values are in Logan and Sangamon Counties, central Illinois, and Harrison County, Indiana (appendix C, pl. 7). The lowest $\overline{R}_o$ values (less than 0.50 percent) are mostly found in the west and adjacent to the northern subcrop belt (pl. 7).

Two regions with significantly different thermal maturities are separated by the Cottage Grove and Rough Creek Fault Systems. The reflectance values from the two regions have distinctly different depth versus $\overline{R}_o$ trends (fig. 15). The shaded trend with $\overline{R}_o$ values less than 0.80 percent is the regional $\overline{R}_o$ gradient for the northern three-fourths of the Illinois Basin. The values to the right of the trend represent samples from the mineralized and intruded area near the Fluorspar Area Fault Complex in southeastern Illinois, and illustrate departures from the regional burial gradient caused by hydrothermal heating.

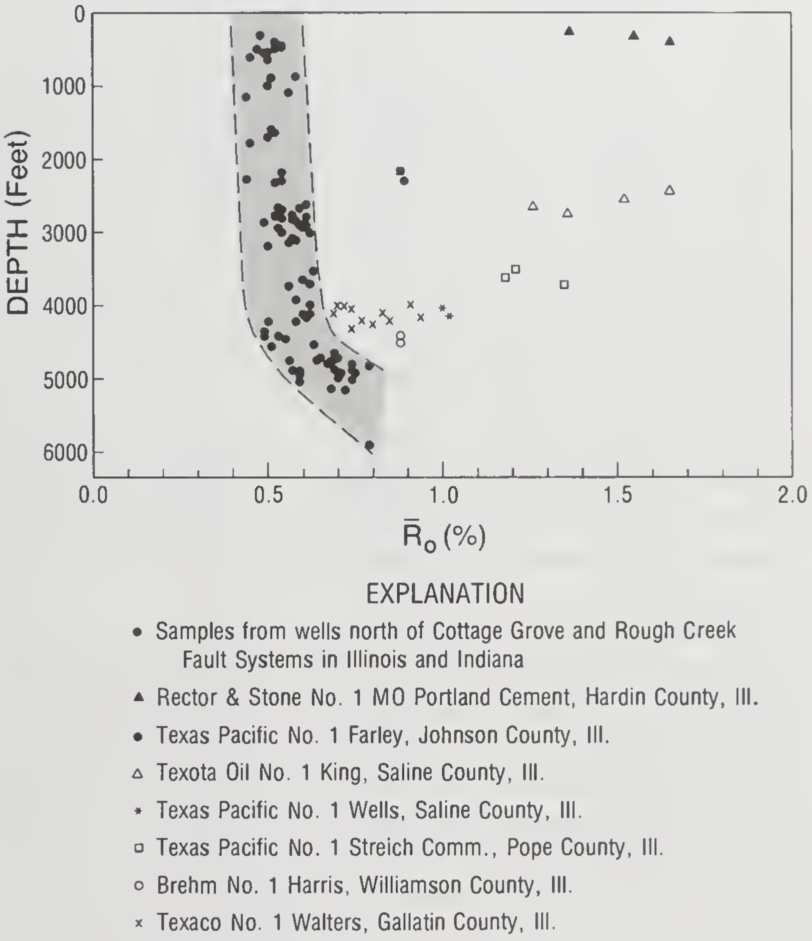


Figure 15. Graph of mean random vitrinite reflectance ($\overline{R}_o$) versus present depth of burial. Shaded area is the gradient for most of the Illinois Basin. The regional trend curves at depth because $\overline{R}_o$ increases exponentially with a linear increase in temperature (Hunt, 1979). Values to the right of the trend are from locations south of the Cottage Grove and Rough Creek Fault Systems in the vicinity of the Fluorspar Area Fault Complex (pl. 1).

North of the Cottage Grove and Rough Creek Fault Systems, $\bar{R}_o$ values are less than 0.80 percent and generally increase with increasing paleoburial depths (Barrows and Cluff, 1984) (fig. 15, pl. 7). The highest maturities in this region (between 0.70 and 0.80 percent $\bar{R}_o$) are along the southward plunging syncline between the Clay City Anticline on the west and the La Salle Anticlinorium on the east (Barrows and Cluff, 1984) (pl. 7). The deepest part of the Illinois Basin lies near the southern end of this syncline in Hamilton and Wayne Counties, Illinois (pl. 3), and has average $\bar{R}_o$ values between 0.63 and 0.76 percent (pl. 7).

$\bar{R}_o$ values less than 0.80 percent are also present south and east of the Moorman Syncline in Kentucky. The $\bar{R}_o$ values in this region are assumed to represent maturation resulting from burial with a thermal gradient and heat flow comparable to those north of the Cottage Grove and Rough Creek Fault Systems.

In southeastern Illinois, $\bar{R}_o$ values are locally much greater than 0.80 percent (fig. 15, pl. 7). The presence of hydrothermal mineralization and small igneous intrusions in Hardin and Pope Counties, Illinois, indicates that anomalously high heat flow caused thermal maturation in this region (Barrows and Cluff, 1984). Igneous intrusions were probably emplaced during the early Permian (Damberger, 1971, 1974; Nelson and Lumm, 1984, 1987). Analyses of core samples from the Rector & Stone No. 1 Missouri (MO) Portland Cement well (well identification number 11IL) located on the flank of Hicks Dome illustrate the high level of thermal maturity in this region, with average $\bar{R}_o$ and T_{MAX} values of 1.50 percent and 455°C, respectively (appendix C, table 9). Although these samples plot along the track for Type III kerogen (fig. 14c), they may, in fact, contain little or no Type III kerogen because the determination of organic matter type using a modified van Krevelen diagram is valid only for low-maturity samples (Tissot and Welte, 1984). Thermally mature samples with high oxygen indices typically contain kerogen that has been oxidized (Peters, 1986). At the Hicks Dome locality, oxidation of kerogen was apparently caused by hot fluids emanating from the magmatic intrusions.

Thirty-five core samples obtained from six wells have been analyzed for both T_{MAX} and $\bar{R}_o$ (table 9), and the correlations between T_{MAX} versus $\bar{R}_o$ and T_{MAX} versus depth are plotted for comparison (figs. 16, 17). Twenty-seven samples have T_{MAX} values greater than 435°C and are thermally mature according to the hydrocarbon generation scale of Peters (1986). Twenty-four samples are in the range for oil and associated gas generation (435°–445°C) and three are in the range for gas generation (445°–470°C). All but two of the eight samples having T_{MAX} values less than 435°C are from the Grassy Creek Shale and Clegg Creek Members (fig. 17, table 9). Also, T_{MAX} values decrease abruptly in Grassy Creek and Clegg Creek intervals of some cores compared with those in both underlying and overlying strata (table 9). Comparable variations are not apparent in the corresponding $\bar{R}_o$ data (table 9). These observations suggest that significant differences in T_{MAX} at a given locality may be related to stratigraphic differences in organic facies (namely, organic matter type) rather than differences in thermal maturity.

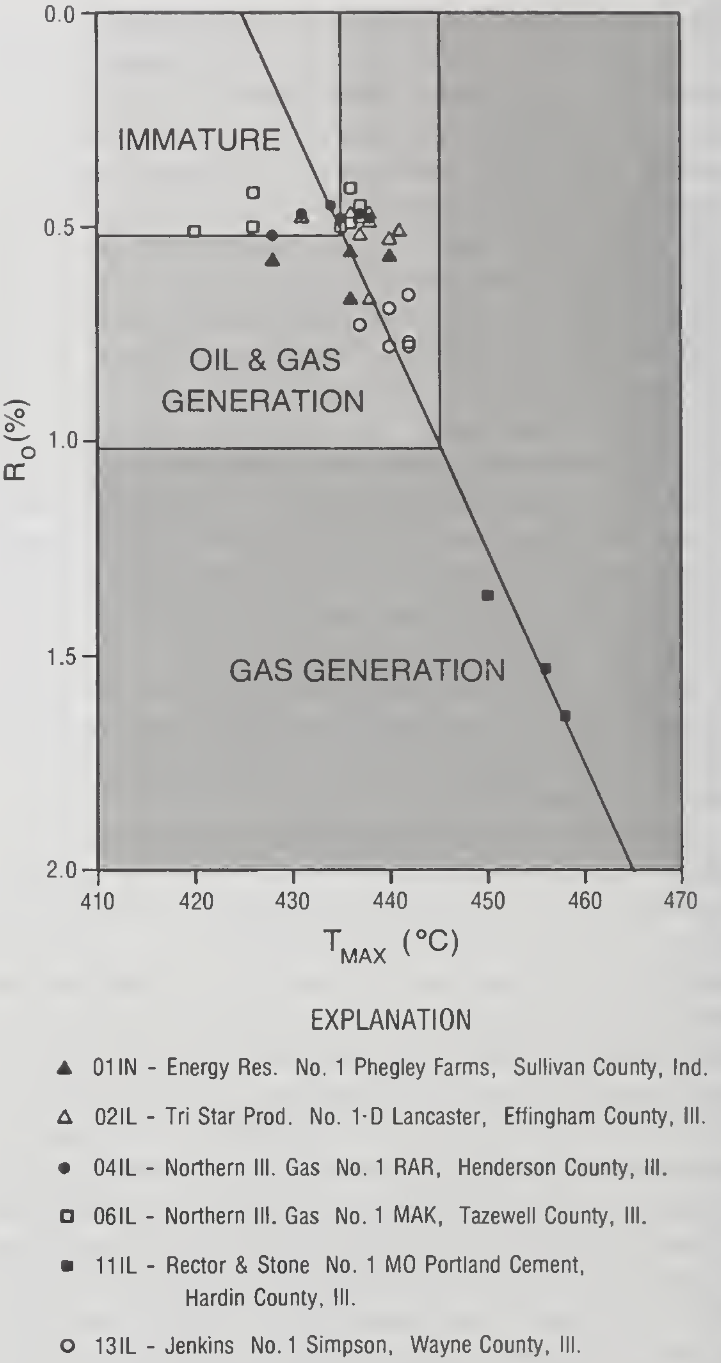


Figure 16. Graph showing Rock-Eval® T_{MAX} versus mean random vitrinite reflectance ($\bar{R}_o$). Petroleum generation begins at T_{MAX} = 435°C (Peters, 1986) and is indicated in some New Albany Shale samples with $\bar{R}_o$ values between 0.41 and 0.50 percent. The sloping line represents the linear regression of the data and has the equation $T_{MAX}=19.65\ \bar{R}_o + 424.6$. T_{MAX} data are for core samples (Chou and others, 1991) (table 9).

Ten of the 35 samples (nearly 30 percent) have T_{MAX} values greater than 435°C and $\bar{R}_o$ values between 0.41 and 0.50 percent (table 9). Conventional interpretation based only on the $\bar{R}_o$ values would underestimate the thermal maturity of these samples by about 0.10 to 0.20 percent $\bar{R}_o$. Rocks with $\bar{R}_o$ values in this low range are generally interpreted to be immature or marginally mature for petroleum generation (Tissot and Welte, 1984). Rocks with $\bar{R}_o$ less than 0.50 percent and T_{MAX} greater than 435°C have three possible explanations: (1) $\bar{R}_o$ values may be suppressed;

Table 9. Rock-Eval® T_{MAX} values for core samples with corresponding mean random vitrinite reflectance ($\overline{R}_o$) data. See appendix C for average $\overline{R}_o$. Modified from Chou and others (1991).

Core Designation	Sample Number	Member	Depth (Feet)	TOC (Wt%)	$\overline{R}_o$ (%)	T_{MAX} (°C)
01IN* (Phegley)	1C1	Clegg Creek	2,504.2	12.96	0.67	436
	3C3	Clegg Creek	2,528.2	9.94	0.56	436
	4C1	Clegg Creek	2,531.4	11.69	0.58	428
	8C2	Morgan Trail	2,579.0	7.11	0.57	440
02IL	1C1	Saverton and Hannibal	3,011.4	1.61	0.67	438
	2C1	Saverton and Hannibal	3,021.4	2.37	0.52	437
	3C1	Grassy Creek	3,043.3	6.64	0.49	438
	4C2	Grassy Creek	3,059.5	8.45	0.47	438
	5C1	Grassy Creek	3,065.3	9.21	0.48	431
	5L2	Grassy Creek	3,071.5	2.54	0.47	436
	6C1	Grassy Creek	3,073.4	7.12	0.48	437
	6L2	Sweetland Creek	3,081.1	2.60	0.53	440
	7C1	Sweetland Creek	3,085.5	4.22	0.51	441
04IL	9C1	Saverton and Hannibal	403.5	0.95	0.45	434
	13C1	Saverton and Hannibal	443.2	2.01	0.47	437
	14C1	Saverton and Hannibal	453.05	2.96	0.48	435
	16C1	Grassy Creek	473.1	2.75	0.52	428
	17C1	Grassy Creek	482.35	3.55	0.47	431
	21C1	Sweetland Creek	523.2	1.22	0.48	438
06IL	10C1	Saverton and Hannibal	993.1	0.73	0.50	435
	13C1	Saverton and Hannibal	1,024.1	0.90	0.49	436
	16C1	Saverton and Hannibal	1,053.15	1.13	0.45	437
	18C1	Saverton and Hannibal	1,073.3	4.14	0.50	426
	19C1	Grassy Creek	1,083.2	6.11	0.42	426
	20C1	Grassy Creek	1,093.35	9.52	0.51	420
	25C1	Sweetland Creek	1,143.5	2.81	0.41	436
11IL	12C1	Selmier	164.0	3.26	1.36	450
	18C1	Selmier	230.0	1.81	1.53	456
	21C1	Selmier	260.1	0.43	1.64	458
13IL	6C2	Grassy Creek	5,069.6	5.31	0.78	440
	7C2	Grassy Creek	5,078.1	7.15	0.77	442
	10C1	Grassy Creek	5,100.3	8.67	0.73	437
	19C1	Selmier	5,190.2	2.23	0.78	442
	21C2	Selmier	5,214.0	4.83	0.66	442
	23C4	Selmier	5,239.6	5.48	0.69	440

*Core Designation	State	County	Location	Well Name
01IN (Phegley)	Indiana	Sullivan	14-6N-10W	Energy Resources of Indiana No. 1 Phegley Farms Inc.
02IL	Illinois	Effingham	31-9N-4E	Tri Star Prod. No. 1-D Lancaster
04IL	Illinois	Henderson	32-8N-4W	Northern Illinois Gas No. 1 RAR
06IL	Illinois	Tazewell	8-23N-2W	Northern Illinois Gas No. 1 MAK
11IL	Illinois	Hardin	36-11S-7E	Rector & Stone No. 1 MO Portland Cement
13IL	Illinois	Wayne	17-3S-8E	Jenkins No. 1 Simpson

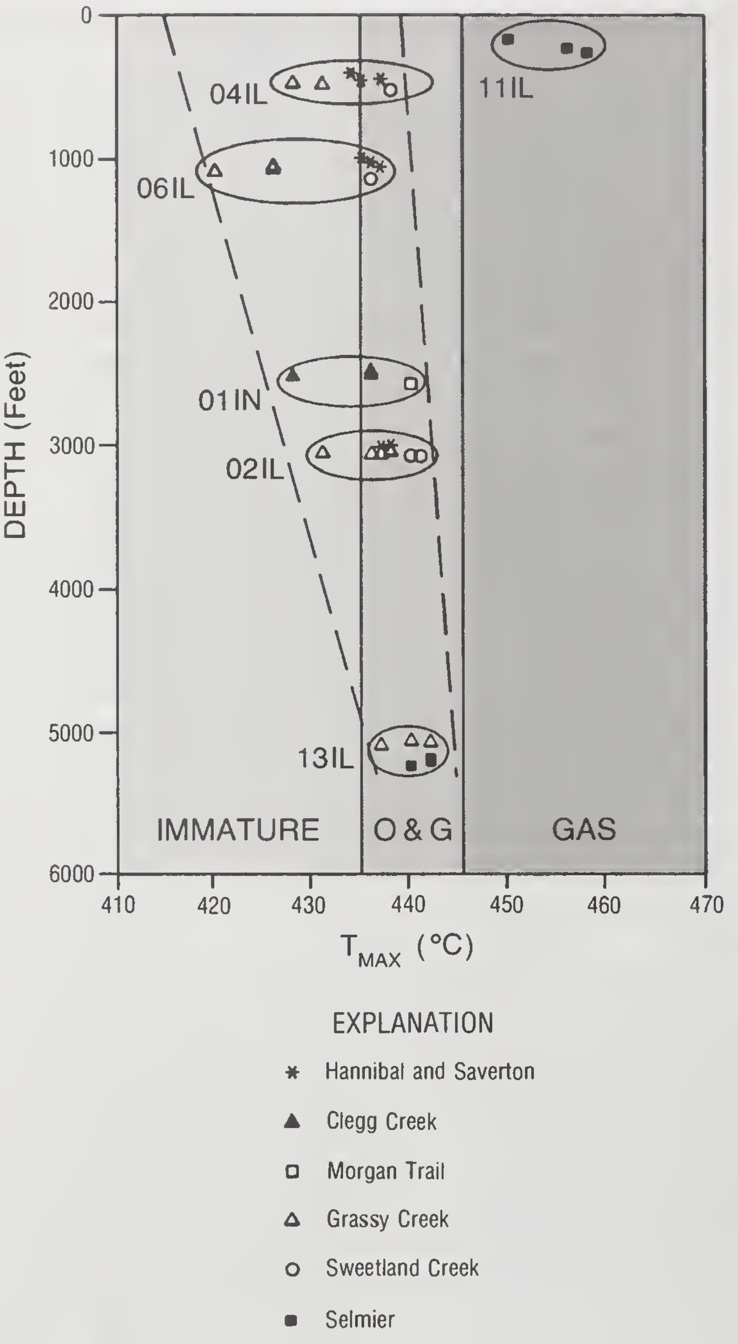


Figure 17. Graph showing Rock-Eval® T_{MAX} versus depth. The dashed trend represents the increase in T_{MAX} due to increasing depth of burial. Samples are the same as in figure 16.

(2) the vitrinite is a type uniquely different from that occurring in Pennsylvanian coals; or (3) the kerogen is a fast-reacting type that generates petroleum at unusually low thermal maturity (for example, high-sulfur, Type II-S kerogen [Tissot and others, 1987]). These possibilities are supported by linear regression analysis, in that thermal generation of petroleum appears to begin at an $\overline{R}_o$ value of 0.53 percent in the New Albany Shale (fig. 16). However, the T_{MAX} data also suggest that some beds in the New Albany, especially in the Grassy Creek Shale and Clegg Creek Members, contain a type of kerogen that generates petroleum at reported $\overline{R}_o$ values as low as 0.41 percent (table 9).

Stable carbon isotope ratios of the methane in off-gas from New Albany Shale cores are another indication of thermal maturity. Published $\delta^{13}C$ values for the methane in 84 canisters containing core samples of the New Albany Shale ranged from -41.7 to -56.0 per mil and have been interpreted as indicating a low maturity and a thermal origin for New Albany Shale gas (Coleman, 1980). Biogenic gas forms only at shallow depths (less than 3,300 feet), is almost pure methane, and has $\delta^{13}C$ values typically more negative than -55 per mil, whereas thermogenic gas forms mostly at greater depths, contains C_2 to C_5 hydrocarbons, and has $\delta^{13}C$ values typically less negative than -55 per mil (Schoell, 1983; Tissot and Welte, 1984). The $\delta^{13}C$ values recorded by the U.S. Geological Survey (Hatch, personal commun.) are between -50.7 and -57.0 per mil (table 10) and support the observations of Coleman (1980). When represented on a diagram of $\delta^{13}C$ versus $C_1/(C_1$ to $C_5)$, off-gas from the New Albany plots along the low maturity boundary for thermogenic gas (fig. 18). The shallowest samples (less than 250 feet) have the most negative $\delta^{13}C$ values (less than -54 per mil) (fig. 19a) and are methane enriched (fig. 19b). Also, the $\delta^{13}C$ values progressively increase with increasing proportions of heavier hydrocarbons (C_2 to C_5) and decreasing proportions of methane (C_1) (fig. 19b). These data indicate that the shallowest New Albany Shale beds may have a small biogenic gas component, but most of the gas is of thermogenic origin associated with oil generation.

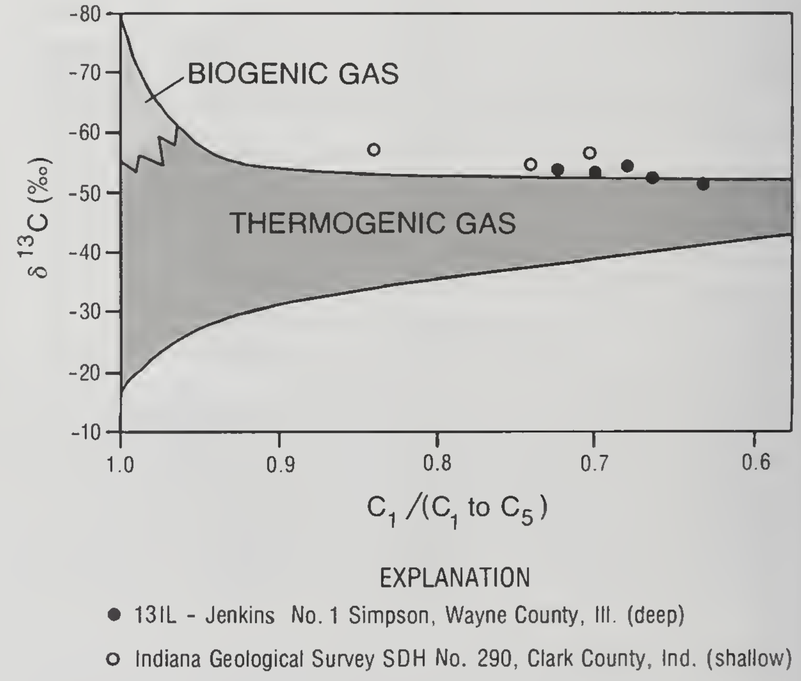


Figure 18. Plot of $\delta^{13}C$ versus $C_1/(C_1$ to $C_5)$ for off-gas from the New Albany Shale core samples. Data are from table 10. Posted values indicate that the gas has low thermal maturity and a thermogenic origin. The boundaries for biogenic and thermogenic gas are from Tissot and Welte (1984).

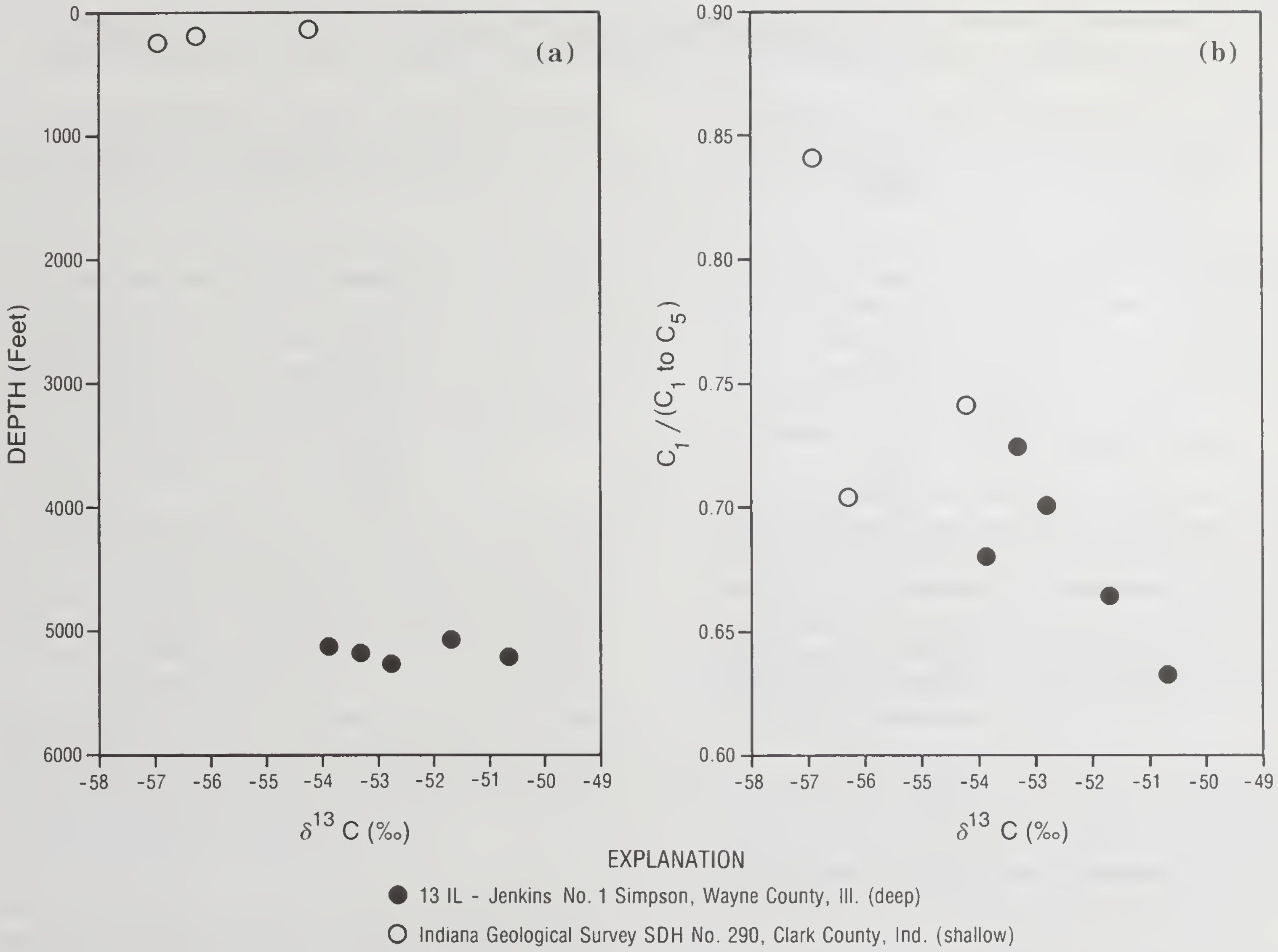


Figure 19. Graphs showing $\delta^{13}C$ versus depth and composition for off-gas from the New Albany Shale. (a) $\delta^{13}C$ versus depth, and (b) $\delta^{13}C$ versus gas composition. Gas samples with $\delta^{13}C$ values less than -54 per mil (‰) and with the highest proportions of methane occur at shallow depths and may have a small biogenic component. Samples are the same as in figure 18.

Relation to Gas Production

Gas production and shows in the New Albany Shale are mostly from the organic-rich units—the Grassy Creek (Shale) and Clegg Creek Members—and the gas is probably indigenous. However, in the vicinity of the commercial gas fields, source beds in the New Albany are not at the level of thermal maturity commonly cited when defining peak gas generation (namely, between about 1.3 and 2.0 percent $\overline{R}_o$ [Tissot and Welte, 1984]). Many New Albany Shale fields are found in areas where the $\overline{R}_o$ values are less than 0.60 percent, and there is no direct relationship between areas with gas production and high reflectance values (pl. 7). In contrast, published studies indicate that in many parts of the Illinois Basin source beds in the New Albany have reached the level of thermal maturity commonly cited for oil generation (namely, between about 0.5 and 1.3 percent $\overline{R}_o$ [Tissot and Welte, 1984]). Hatch and others (1991) concluded that more than 99 percent of Illinois Basin oil was derived from the New Albany Shale. Furthermore, production of minor amounts of oil from the New Albany Shale or equivalent Chattanooga Shale has been recorded from more than 15 fields in western and south-central Kentucky (Nuttall, 1989a), and New Albany Shale gas commonly contains significant amounts of associated heavier hydrocarbons (tables 5, 10). Together, these observations suggest that, although some gas may have migrated laterally from areas of high thermal maturity, most if not all of the gas in the New Albany Shale was generated locally at the same time as oil.

Table 10. Carbon isotope ratios and composition of off-gas from canned cores of the New Albany Shale. Unpublished data compiled during the Eastern Gas Shales Project by the U.S. Geological Survey, George E. Claypool, Principal Investigator.

Core Designation	Depth (Feet)	$\delta^{13}C$ (‰)	$C_1/(C_1$ to $C_5)$	C_1 (%)
13IL*	5,065	-51.7	0.66	65.95
	5,116	-53.9	0.68	66.93
	5,166	-53.3	0.72	71.16
	5,216	-50.7	0.63	62.13
	5,265	-52.8	0.70	69.44
SDH No. 290	145	-54.2	0.74	63.48
	195	-56.3	0.70	60.76
	237	-57.0	0.84	76.80

*Core Designation	State	County	Location	Well Name
13IL	Illinois	Wayne	17-3S-8E	Jenkins No. 1 Simpson
SDH No. 290	Indiana	Clark	283 CMG-2N-7E	Clark County State Forest

SUMMARY AND CONCLUSIONS

- The New Albany Shale in the Illinois Basin has promising gas production potential because of its high estimated gas content (86 TCF) and long history of production.

- The New Albany Shale is a continuous unit recognized throughout the subsurface in the Illinois Basin. The elevation of the top of the New Albany ranges from about 750 feet above sea level near the outcrop to more than 4,500 feet below sea level in southeastern Illinois (Hamilton County). The formation is thickest in southeastern Illinois (Hardin County) and western Kentucky (Union and Crittenden Counties), where it is locally more than 460 feet thick.

- The New Albany Shale is affected by complex faulting in western Kentucky and adjacent parts of Illinois and Indiana. Elsewhere, less intense deformation has locally produced folds and faults that influence its elevation and thickness (pls. 1, 3, 4).

- The New Albany Shale is subdivided into 13 members and 5 beds, some of which are recognized only locally. For the purpose of subsurface correlation, the New Albany is divided into eight unique geophysical units that can be recognized throughout the basin (fig. 2, pl. 5).

- The New Albany is composed mostly of various shades of greenish-gray, brownish-black, or grayish-black shale. Beds of siltstone, sandstone, limestone, and dolostone are present, but they are limited in extent and thickness.

- The dark-colored shale layers typically have parallel laminae, more than 2.5 weight percent organic carbon, amorphous (Type II) kerogen, high radioactivity, and high concentrations of natural gas released from cores. The lighter-colored shale layers commonly have bioturbated fabric, 1 to 2 weight percent organic carbon, humic (Type III) kerogen, moderate radioactivity, and lower concentrations of natural gas released from cores.

- Gas has been produced from the New Albany Shale since 1858, from at least 40 fields in Kentucky, 19 in Indiana, and 1 in Illinois. Production data are not publicly available, and none have been disclosed by operators to date. Only IP data are generally available. Measured IP values for New Albany Shale wells range from less than 10 to 4,500 MCFGPD and average 187 MCFGPD.

- Gas production is developed mainly in relatively organic-rich shale beds of the Grassy Creek (Shale), Clegg Creek, and Blocher (Shale) Members. The limited evidence that production, where known, comes from the most organic-rich shale beds suggests that the gas produced from the New Albany is indigenous.

- New Albany Shale gas is predominantly methane with significant and variable amounts of heavier hydrocarbons. Oil is occasionally produced in small amounts from the New Albany and the stratigraphically equivalent Chattanooga Shale in south-central Kentucky. Water generally is not produced in Kentucky, but is co-produced with gas in Indiana and along the Indiana and Kentucky border.

- The New Albany Shale reservoir contains natural gas both as free gas in open pore space, and as adsorbed gas on interior clay and kerogen surfaces. Analyses of New Albany Shale core samples from Sangamon, Effingham, and Tazewell Counties, Illinois, and from Christian County, Kentucky, indicate that between 30 and 80 percent of the methane in the shale was adsorbed gas, with the fraction of adsorbed gas showing a strong dependence on pressure.

- Natural fracturing is essential for effective reservoir permeability. In fields where detailed studies have been undertaken, fracturing appears to be related to structures such as faults, flexures, and local or regional carbonate buildups over which the shale is draped and compacted.

- Commercial production of gas from the New Albany Shale requires well stimulation that interconnects the well bore with the natural fracture system. Effective stimulation maintains permeability by introducing a proppant into the pressure-sensitive fractures near the well bore. Current stimulations are hydraulic-fracture treatments using nitrogen foam with a proppant; these treatments have replaced the older gelatinated nitroglycerine explosive shots.

- The amount of organic carbon in the New Albany Shale is quite variable, ranging from near 0 weight percent in greenish-gray beds to 25 weight percent in brownish-black organic-rich beds; 86 percent of the samples analyzed by Frost (1980) contain more than 1.0 weight percent organic carbon and 97 percent contain more than 0.5 weight percent organic carbon. More than 90 percent of the organic matter is amorphous; the remainder is composed of vitrinite, liptinite, and inertinite. Rock-Eval® data indicate that the New Albany Shale contains mostly Type II kerogen that still has substantial oil- and gas-generating potential.

- The inorganic portion of the New Albany Shale is relatively uniform in composition, except for the carbonate and pyrite content, which are variable. The mineralogy and inorganic chemistry vary stratigraphically from bed to bed, but they are typically uniform within a given bed.

- The dominant clay mineral in the New Albany Shale is illite. Other clay minerals, including chlorite and expandable clays, are present in varying but smaller proportions. The remaining components of the mineral fraction are quartz; calcite and dolomite; pyrite and minor marcasite; minor amounts of potassium feldspar, plagioclase, and muscovite mica; and traces of apatite, siderite, and heavy minerals (rutile, zircon, glauconite, amphibole, and pyroxene).

- Where the data exist, the mean random vitrinite reflectance ($\overline{R}_o$) values measured on New Albany Shale samples in or near the commercial gas fields are low (less than 0.7 percent) and below the conventionally accepted range for the main stage of thermal generation of natural gas (0.7 to 2.0 percent). Carbon-isotope-ratio data for methane in the off-gas from cores show that New Albany Shale gas is of low maturity, has a thermogenic origin, and is associated with oil generation. The presence of heavier hydrocarbons (C_2 to C_5) in produced gas and off-gas confirms this conclusion.

- The $\overline{R}_o$ data for the New Albany Shale (appendix C, pl. 7) indicate, in general, the relative thermal maturity of these beds, although some $\overline{R}_o$ values may be suppressed. High-reflectance data, greater than 0.8 percent, occurring in the southern part of the basin are related to periods of high heat flow associated with mineralization and magmatism in the vicinity of the Fluorspar Area Fault Complex and at Hicks Dome. Elsewhere in the basin, $\overline{R}_o$ values are less than 0.8 percent and mostly reflect heating due to burial where there was a normal thermal gradient.

- T_{MAX} values indicate that some thermally mature beds in the New Albany have $\overline{R}_o$ values between 0.41 and 0.50 percent. Statistically, thermal generation of hydrocarbons begins in the New Albany at an $\overline{R}_o$ value of 0.53 percent. Markedly lower T_{MAX} values within a given section reflect variations in organic-matter composition and suggest the presence, particularly in some organic-rich units in the Grassy Creek (Shale), Clegg Creek, and Blocher (Shale) Members, of a rapidly reacting kerogen capable of generating petroleum at unusually low thermal maturity.

- Criteria that operators may use to identify areas where the New Albany Shale is likely to have the greatest gas-production potential are the presence of: (1) high organic-carbon content in the shale, (2) thick organic-rich shale intervals, (3) high radioactivity on the gamma-ray log and low density on the density log, which are generally indicative of organic-rich intervals, (4) natural fractures in the shale, (5) structural features where associated fracturing is likely, (6) proximity to historic production, and (7) thermally mature shale with T_{MAX} of 435°C and $\overline{R}_o$ of 0.53 percent or greater.

- Deterrents to gas exploration and development in the New Albany Shale that need to be overcome include: (1) absence of current exploration and production activity, (2) inadequate gas pipeline infrastructure, (3) lack of gas production data, and (4) large tracts of acreage leased by coal companies.

- Future work needed to generate interest and to further define the gas potential of the New Albany Shale includes: (1) analyzing core to better determine the properties of the shale reservoir, (2) obtaining geophysical logs designed for evaluating fracture systems, (3) acquiring production data from operators, (4) conducting site evaluations in cooperation with private operators, (5) analyzing gas composition, particularly produced gas, for C_1 to C_5 hydrocarbons, carbon dioxide, and $\delta^{13}C$, (6) determining the amount and chemistry of water in New Albany Shale reservoirs, (7) determining whether anomalous heating events influenced the development of commercial gas reservoirs, (8) determining the specific kerogen type that accounts for New Albany Shale gas and the thermal maturity required to generate commercial volumes of gas, and (9) mapping of lithofacies and organic facies to delineate the location of mature, organic-rich, gas-prone intervals within the formation.

ACKNOWLEDGMENTS

We thank Citizens Gas Corporation for supplying gas-content data for samples from two New Albany Shale cores from Greene County, Indiana. We thank the Illinois State Geological Survey for permitting the inclusion of unpublished mean random vitrinite reflectance measurements determined by Mary H. Barrows and J. Wesley Dillon. Additional information about thermal maturity was derived from unpublished stable-carbon-isotope-ratio ($\delta^{13}C$) data compiled by George E. Claypool, Principal Investigator, at the U.S. Geological Survey during the Eastern Gas Shales Project. Joan C. Crockett provided valuable assistance by gathering data from the geochemical files at the Illinois State Geological Survey. Unpublished data relating to inorganic carbon, total sulfur, and carbon dioxide were kindly furnished by the Geochemistry Section at the Indiana Geological Survey. Much of these data was compiled during the Eastern Gas Shales Project under the guidance of Richard K. Leininger. Computer mapping assistance was provided by Scott Olt and Colin G. Treworgy of the Illinois Survey.

The suggestions made by the following critical reviewers at the three surveys are much appreciated: Richard D. Harvey, Michael L. Sargent, Heinz H. Damberger, Donald F. Oltz, and Janis D. Treworgy of the Illinois State Geological Survey; Curtis A. Ault, Stanley J. Keller, and John A. Rupp of the Indiana Geological Survey; and James A. Drahovzal, James C. Cobb, Brandon C. Nuttall, and Margaret L. Smath of the Kentucky Geological Survey. Lisa M. Pratt and Edward M. Ripley of the Indiana University Department of Geological Sciences kindly reviewed the sections, "Source Rock Potential" and "Mineralogy and Geochemisty," respectively. We gratefully acknowledge the discussions with and suggestions from David G. Hill, Gas Research Institute, who also critically reviewed the manuscript and plates.

The editorial skills of Deborah A. DeChurch and the word processing skills of Marilyn DeWees, both of the Indiana Geological Survey, are much appreciated. The text figures and the map and cross section plates were drafted by the following members of the Drafting Section of the Indiana Geological Survey: Roger L. Purcell, Kimberly H. Sowder, Kari Ann Lancaster, Wilbur E. Stalions, and Eric P. Hartke. Photographic work was performed by Barbara T. Hill and John M. Day of the Photography/Reprographics Section of the Indiana Survey.

REFERENCES CITED

Adam, N. K., 1941, Solid surfaces: fine structure, adsorption, and catalysis, *in* The physics and chemistry of surfaces: Oxford, U.K., Oxford University Press, p. 232-299.

Atherton, E., Collinson, C., and Lineback, J. A., 1975, Mississippian System, *in* Willman, H. B., Atherton, E., Buschbach, T. C., Collinson, C., Frye, J. C., Hopkins, M. E., Lineback, J. A., and Simon, J. A., Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, p. 123-163.

Ault, C. H., 1990, Directions and characteristics of jointing in the New Albany Shale (Devonian-Mississippian) of southeastern Indiana, *in* Proceedings, 1989 Eastern Oil Shale Symposium: Lexington, University of Kentucky, Kentucky Center for Applied Energy Research, IMMR89/201, p. 239-252.

Ault, C. H., Becker, L. E., Droste, J. B., Keller, S. J., and Shaver, R. H., 1992, Map of Indiana showing thickness of Silurian rocks and locations of reefs: Indiana Geological Survey Miscellaneous Map 54, scale 1:500,000.

Barrows, M. H., and Cluff, R. M., 1984, New Albany Shale Group (Devonian-Mississippian) source rocks and hydrocarbon generation in the Illinois Basin, *in* Demaison, G., and Murris, R. J., eds., Petroleum geochemistry and basin evaluation: American Association of Petroleum Geologists Memoir 35, p. 111-138.

Barrows, M. H., Cluff, R. M., and Harvey, R. D., 1979, Petrology and maturation of dispersed organic matter in the New Albany Shale Group of the Illinois Basin: Proceedings for Third Eastern Gas Shales Symposium, October 1979, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-79/6, p. 85-114.

Barrows, M. H., Cluff, R. M., and Harvey, R. D., 1980, Organic petrography, *in* Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC/12142-26, p. 63-75.

Bassett, J. L., and Hasenmueller, N. R., 1977, The New Albany Shale and correlative strata in Indiana, *in* Enhanced oil and gas recovery and improved drilling methods: Tulsa, Okla., Energy Research and Development Administration, p. G-11/1 to G-11/9; 1978, Proceedings [for] First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 183-194.

Bassett, J. L., and Hasenmueller, N. R., 1979a, Map showing structure on base of New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, EGSP Series No. 800, scale 1:500,000.

Bassett, J. L., and Hasenmueller, N. R., 1979b, Map showing structure on top of New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, EGSP Series No. 801, scale 1:500,000.

Bassett, J. L., and Hasenmueller, N. R., 1980, Map of Indiana showing thickness of the Ellsworth Member of the New Albany Shale (Devonian and Mississippian): Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 810, scale 1:500,000.

Bassett, J. L., and Hasenmueller, N. R., 1981, Gas production, *in* Hasenmueller, N. R., and Woodward, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 85-92; 1982, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 85-92.

Baxter, J. W., and Desborough, G. A., 1965, Areal geology of the Illinois Fluorspar District, part 2, Karbers Ridge and Rosiclare Quadrangles: Illinois State Geological Survey Circular 385, 40 p.

Baxter, J. W., Desborough, G. A., and Shaw, C. W., 1967, Areal geology of the Illinois Fluorspar District, part 3, Herod and Shetlerville Quadrangles: Illinois State Geological Survey Circular 413, 41 p.

Beard, J., 1980, Devonian black shale study of western Kentucky, final status report: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, Contract EW-78-S-21-8215, 113 p.

Becker, L. E., and Keller, S. J., 1976, Silurian reefs in southwestern Indiana and their relation to petroleum accumulation: Indiana Geological Survey Occasional Paper 19, 11 p.

Beier, J. A., and Hayes, J. M., 1989, Geochemical and isotopic evidence for paleoredox conditions during the deposition of the Devonian-Mississippian New Albany Shale, southern Indiana: Geological Society of America Bulletin, v. 101, p. 774-782.

Bell, A. H., and Workman, L. E., 1928, The Media Anticline, Henderson County, Illinois: Illinois State Geological Survey Illinois Petroleum 13, 11 p.

Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., 1980, Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC/12142-26, 183 p.

Bertagne, A. J., and Leising, T. C., 1991, Interpretation of seismic data from the Rough Creek Graben of western Kentucky and southern Illinois *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 199-208.

Bethke, C. M., Reed, J. D., and Oltz, D. F., 1991a, Long-range petroleum migration in the Illinois Basin *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 455-472.

Bethke, C. M., Reed, J. D., and Oltz, D. F., 1991b, Long-range petroleum migration in the Illinois Basin: American Association of Petroleum Geologists Bulletin, v. 75, p. 925-945.

Bickford, M. E., Van Schmus, W. R., and Zietz, I., 1986, Proterozoic history of the Midcontinent region of North America: Geology, v. 14, p. 492-496.

Black, D. F. B., 1986, Oil in dolomitized limestone reservoirs in Kentucky, *in* Aldrich, M. J., Jr., and Laughlin, A. W., eds., Proceedings of the Sixth International Conference on Basement Tectonics, Santa Fe, N. Mex., September 16-20, 1985: Salt Lake City, Utah, International Basement Tectonics Association, p. 140-152.

Bois, C., Bouche, P., and Pelet, R., 1982, Global geologic history and distribution of hydrocarbon reserves: American Association of Petroleum Geologists Bulletin, v. 66, p. 1248-1270.

Bookout, J. F., Chairman, 1980, Unconventional gas sources - Volume III, Devonian Shales: National Petroleum Council Committee on Unconventional Gas Sources.

Borden, W. W., 1874, Report of a geological survey of Clarke and Floyd Counties, Indiana: Indiana Geological Survey Annual Report 5, p. 133-189.

Braile, L. W., Hinze, W. J., Sexton, J. L., Keller, G. R., and

Lidiak, E. G., 1984, Tectonic development of the New Madrid Seismic Zone: U.S. Geological Survey Open-File Report 84-770, p. 204-233.

Branam, T. D., Comer, J. B., Shaffer, N. R., Ennis, M. V., and Carpenter, S. H., 1991, Inorganic ground-water chemistry at an experimental New Albany Shale (Devonian-Mississippian) in situ gasification site, Clark County, Indiana, *in* Proceedings, 1990 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR90/201, p. 452-462; Fuel, v. 70, p. 1317-1323.

Bristol, H. M., 1968, Structure of the base of the Mississippian Beech Creek (Barlow) Limestone in Illinois: Illinois State Geological Survey Illinois Petroleum 88, 12 p.

Bristol, H. M., and Treworgy, J. D., 1979, The Wabash Valley Fault System in southeastern Illinois: Illinois State Geological Survey Circular 509, 19 p.

Buiskool Toxopeus, J. M. A., 1983, Selection criteria for the use of vitrinite reflectance as a maturity tool, *in* Brooks, J., ed., Petroleum geochemistry and exploration of Europe: Oxford, U.K., Blackwell Scientific Publications, p. 295-307.

Buschbach, T. C., and Kolata, D. R., 1991, Regional setting of Illinois Basin, *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 29-55.

Campbell, G., 1946, New Albany Shale: Geological Society of America Bulletin, v. 57, p. 829-908.

Carr, D. D., 1981, Lineament analysis, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 62-69; Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 45-52.

Chen, P.-Y., and Shaffer, N. R., 1978, Petrography and clay mineralogy of the New Albany Shale from Indiana: Fifteenth Annual Clay Minerals Society Meeting Programs and Abstracts, Bloomington, Ind., p. 7.

Chou, M.-I. M., and Dickerson, D. R., 1985, Organic geochemical characterization of the New Albany Shale Group in the Illinois Basin: Organic Geochemistry, v. 8, p. 413-420.

Chou, M.-I. M., Dickerson, D. R., Chou, S.-F. J., and Sargent, M. L., 1991, Hydrocarbon source potential and organic geochemical nature of source rocks and crude oils in the Illinois Basin: Illinois State Geological Survey Illinois Petroleum 136, 39 p.

Claypool, G. E., and Threlkeld, C. N., 1978, Chemical and isotopic composition of gas from Devonian black shale canned core samples, Martin County, Kentucky, and Wise County, Virginia: Proceedings, [for] First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 596-607.

Claypool, G. E., Threlkeld, C. N., and Bostick, N. H., 1978, Natural gas occurrence related to regional thermal rank of organic matter (maturity) in Devonian rocks of the Appalachian Basin: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 54-65.

Cluff, R. M., 1980, Paleoenvironment of the New Albany Shale Group (Devonian-Mississippian) of Illinois: Journal of Sedimentary Petrology, v. 50, p. 767-780.

Cluff, R. M., and Byrnes, A. P., 1991, Lopatin analysis of maturation and petroleum generation in the Illinois Basin *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 425-454.

Cluff, R. M., and Dickerson, D. R., 1982, Natural gas potential of the New Albany Shale Group (Devonian-Mississippian) in southeastern Illinois: Proceedings of the 1980 Society of Petroleum Engineers/U.S. Department of Energy Symposium on Unconventional Gas Recovery, Pittsburgh, Pa., May 18–19, 1980, p. 21-25, Society of Petroleum Engineers Technical Paper 8924; Illinois State Geological Survey Reprint 1980-G; Society of Petroleum Engineers Journal, v. 22, p. 291-300.

Cluff, R. M., Reinbold, M. L., and Lineback, J. A., 1981, The New Albany Shale Group of Illinois: Illinois Geological Survey Circular 518, 83 p.

Coleman, D. D., 1980, Carbon isotope analysis of off-gases, *in* Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC/12142-26, p. 135-141.

Collett, J., 1879, Geological report on Harrison and Crawford Counties, Indiana: Indiana Geological Survey Annual Reports 8, 9, and 10, p. 291-522.

Collinson, C., and Atherton, E., 1975, Devonian System, *in* Willman, H.B., Atherton, E., Buschbach, T. C., Collinson, C., Frye, J. C., Hopkins, M. E., Lineback, J. A., and Simon, J. A., Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, p. 104-123.

Collinson, C., Becker, L. E., James, G. W., Koenig, J. W., and Swann, D. H., 1967, Devonian of the north-central region, United States, *in* International Symposium on the Devonian System: Alberta Society of Petroleum Geologists, v. 1, p. 933-971; Illinois State Geological Survey Reprint 1968-G.

Collinson, C., Rexroad, C. B., and Thompson, T. L., 1971, Conodont zonation of the North American Mississippian: Geological Society of America Memoir 127, p. 353-395.

Collinson, C., Scott, A. J., and Rexroad, C. B., 1962, Six charts showing biostratigraphic zones and correlations based on conodonts from the Devonian and Mississippian rocks of the upper Mississippi Valley: Illinois State Geological Survey Circular 328, 32 p.

Conkin, J. E., 1986, Late Devonian New Albany-Ohio-Chattanooga Shales and their interbasinal correlation in Indiana, Ohio, Kentucky, and Tennessee, *in* Proceedings, 1985 Eastern Oil Shale Symposium: Lexington, University of Kentucky, Kentucky Center for Energy Research Laboratory KCERL85/147, p. 217-259.

Conkin, J. E., and Conkin, B. M., 1972, Guide to the rocks and fossils of Jefferson County, Kentucky, southern Indiana, and adjacent areas: Louisville, Ky., University of Louisville Printing Services, 331 p.

Conkin, J. E., and Conkin, B. M., 1973, The paracontinuity and the determination of the Devonian-Mississippian boundary in the type lower Mississippian area of North America: Louisville, Ky., University of Louisville Studies in Paleontology and Stratigraphy 1, 36 p.

Conkin, J. E., and Conkin, B. M., 1975, The Devonian-Mississippian and Kinderhookian-Osagean boundaries in the east-central United States are paracontinuities: Louisville, Ky., University of Louisville Studies in Paleontology and Stratigraphy 4, 54 p.

Crouse, C. S., 1925, The precious metal content of the black Devonian shales of Kentucky, *in* Thiessen, R., White, D., and Crouse, C. S., Oil shales of Kentucky: Kentucky Geological Survey Series VI, v. 21, Chapter II, p. 49-58.

Damberger, H. H., 1971, Coalification pattern of the Illinois Basin: Economic Geology, v. 66, p. 488-494.

Damberger, H. H., 1974, Coalification patterns of Pennsylvanian coal basins of the eastern United States, *in* Carboniferous materials as indicators of metamorphism: Geological Society of America Special Paper 153, p. 53-74.

Dawson, T. A., and Carpenter, G. L., 1963, Underground storage of natural gas in Indiana: Indiana Geological Survey Special Report 1, 29 p.

Desborough, G. A., 1992, Mineralogical and geochemical analysis of the metal- and organic-rich Grassy Creek Shale of the New Albany Group (Upper Devonian and Lower Mississippian) in Hardin County, southern Illinois: U.S. Geological Survey Bulletin 1989, p. C1-C10.

Dever, G. R., Jr., and McGrain, P., 1969, High-calcium and low-magnesium limestone resources in the region of the lower Cumberland, Tennessee, and Ohio valleys, western Kentucky: Kentucky Geological Survey, Series X, Bulletin 5, 192 p.

Devera, J. A., and Hasenmueller, N. R., 1991, Kaskaskia sequence, Middle and Upper Devonian Series through Mississippian Kinderhookian Series, *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 113-123.

de Witt, W., Jr., 1981, Revision of the areal extent of the New Albany, Chattanooga, and Ohio Shales in Kentucky, *in* Roberts, T. G., ed., Economic geology, structure, v. 2 *of* Geological Society of America Cincinnati 1981 Field Trip Guidebook: Falls Church, Va., American Geological Institute, p. 331-334.

de Witt, W., Jr., 1986, Devonian gas-bearing shales in the Appalachian Basin, *in* Spencer, C. W., and Mast, R. F., eds., Geology of tight gas reservoirs: American Association of Petroleum Geologists Studies in Geology 24, p. 1-8.

Droste, J. B., and Shaver, R. H., 1980, Recognition of buried Silurian reefs in southwestern Indiana: Application to the Terre Haute Bank: Journal of Geology, v. 88, p. 567-587.

Duffy, J., and Schwalb, H., 1979, Past and current developments for drilling New Albany Shale gas wells in western Kentucky: Proceedings for Third Eastern Gas Shales Symposium, October 1979, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-79/6, p. 403-405.

Ells, G. D., 1978, An appraisal of known Antrim Shale and Berea oil and gas pools in Michigan: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 280-290.

Engelder, T., 1982, Is there a genetic relationship between selected regional joints and contemporary stress within the lithosphere of North America?: Tectonics, v. 1, p. 161-177.

Ettensohn, F. R., Barnett, S. F., and Norby, R. D., 1991, Middle Devonian black shales in Kentucky, *in* Proceedings, 1990 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR90/201, p. 218-226.

Ettensohn, F. R., and Barron, L. S., 1981, Depositional model for the Devonian-Mississippian black shales of North America: A paleoclimatic-paleogeographic approach, *in* Roberts, T. G., ed., Economic geology, structure, v. 2 *of* Geological Society of America Cincinnati 1981 Field Trip Guidebook: Falls Church, Va., American Geological Institute, p. 344-357.

Ettensohn, F. R., and Geller, K. L., 1987, Tectonic control of interbasinal relationships between Devonian black shales of the Illinois and Appalachian Basins of Kentucky, *in* Proceedings, 1986 Eastern Oil Shale Symposium: Lexington, Kentucky Energy Cabinet Laboratory, KECL86-158, p. 303-314.

Ettensohn, F. R., Goodman, P. T., Norby, R. D., and Shaw, T. H., 1989, Stratigraphy and biostratigraphy of the Devonian-Mississippian black shales in west-central Kentucky and adjacent parts of Indiana and Tennessee, *in* Proceedings, 1988 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR88/101, p. 237-245.

Floodgate, G. D., and Judd, A. G., 1992, The origins of shallow gas: Continental Shelf Research, v. 12, no. 10, p. 1145-1156.

Frankie, W. T., Moody, J. R., Kemper, J. R., and Johnston, I. M., 1986a, Geologic and hydrocarbon report of Letcher County: Part 1 of 5, hydrocarbon production from the Devonian shale in Letcher, Knott, Floyd, Martin, and Pike Counties, eastern Kentucky: Kentucky Geological Survey, 59 p.

Frankie, W. T., Moody, J. R., Kemper, J. R., and Johnston, I. M., 1986b, Geologic and hydrocarbon report of Knott County: Part 2 of 5, hydrocarbon production from the Devonian shale in Letcher, Knott, Floyd, Martin, and Pike Counties, eastern Kentucky: Kentucky Geological Survey, 76 p.

Frankie, W. T., Moody, J. R., Kemper, J. R., and Johnston, I. M., 1986c, Geologic and hydrocarbon report of Floyd County: Part 3 of 5, hydrocarbon production from the Devonian shale in Letcher, Knott, Floyd, Martin, and Pike Counties, eastern Kentucky: Kentucky Geological Survey, 49 p.

Frost, J. K., 1980, Chemical analysis of Devonian shales: Organic carbon content, *in* Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC/12142-26, p. 95-105.

Frost, J. K., Zierath, D. L., and Shimp, N. F., 1985, Chemical composition and geochemistry of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Supplement to Final Report to U.S. Department of Energy, Contract DE-AC21-76ET12142, ISGS Contract Report 1985-4, 134 p.

Frost, R. R., and Thomas, J., Jr., 1978, Use of internal surface area and high-pressure methane sorption data to estimate capacity for gas production from the New Albany Shale Group: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 138-148.

Geological Society of America, Rock-color Chart Committee, 1975, Rock-color chart: Geological Society of America, [11] p.

Gray, H. H., Ault, C. H., and Keller, S. J., 1987, Bedrock geologic map of Indiana: Indiana Geological Survey Miscellaneous Map 48, scale 1:500,000.

Gray, J., and Boucot, A, J., 1977, Early vascular land plants: Proof and conjecture: Lethaia, v. 10, p. 145-174.

Gray, J., and Boucot, A, J., 1979, The Devonian land plant *Protosalvinia*: Lethaia, v. 12, p. 57-63.

Guidry, F. K., Luffel, D. L., Lorenzen, J., Curtis, J. B., and Low, P. F., 1991, Formation evaluation technology for production enhancement: Annual technical report October 1990–October 1991: Chicago, Ill., Gas Research Institute, GRI-91-0376, 147 p.

Hailer, J. G., Shaffer, N. R., Leininger, R. K., Yates, M. G., and Ripley, E. M., 1982, Sulfur and carbon isotope trends in the New Albany Shale (Devonian-Mississippian) in Indiana, *in* Proceedings, 1981 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, Report IMMR82/066, p. 127-135.

Hamilton-Smith, T., 1988, Significance of geology to gas production from Devonian shales of the central Appalachian Basin: An underdeveloped asset: Chicago, Ill., Gas Research Institute, GRI-88/0178, 117 p.

Harvey, R. D., Burke, D. A., Barrows, M. H., and Cluff, R. M., 1980, Mineralogy, *in* Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC/12142-26, p. 51-61.

Hasenmueller, N. R., 1982, Resource assessment of the New Albany Shale (Devonian and Mississippian) in southeastern Indiana–Preliminary report, *in* Proceedings, 1981 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR82/066, p. 173-180.

Hasenmueller, N. R., 1989a, Gas production from the New Albany Shale (Devonian and Mississippian) in Indiana: Indiana Geological Survey Memorandum Report NRH2.89, [14] p.

Hasenmueller, N. R., 1989b, Relationship of New Albany Shale (Devonian-Mississippian) and Rockford Limestone (Mississippian) to Silurian reefs in Greene County, Indiana: Geological Society of America Abstracts with Programs, v. 21, p. 167.

Hasenmueller, N. R., 1993, New Albany Shale (Devonian and Mississippian) of the Illinois Basin, *in* Roen, J. B., and Kepferle, R. C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America: U.S. Geological Survey Bulletin 1909-C, 19 p.

Hasenmueller, N. R., and Bassett, J. L., 1981, Stratigraphy, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 5-32; Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 5-32.

Hasenmueller, N. R., Boberg, W. S., Comer, J., Smidchens, Z., Frankie, W. T., Lumm, D. K., and Hamilton-Smith, T., 1991, Evaluation of gas potential of New Albany Shale (Devonian and Mississippian) in the Illinois Basin: Gas Research Institute Project Advisors' Group Meeting, Traverse City, Michigan, September 9-11, 1991, 35 p.

Hasenmueller, N. R., Kepferle, R. C., Matthews, R. D., and Pollock, D., 1983a, *Foerstia* (*Protosalvinia*) in Devonian shales of the Appalachian, Illinois, and Michigan Basins, eastern United States, *in* Proceedings, 1983 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR83/089, p. 41-58.

Hasenmueller, N. R., and Leininger, R. K., 1987, Oil-shale prospects for the New Albany Shale in Indiana: Indiana Geological Survey Special Report 40, 31 p.

Hasenmueller, N. R., Leininger, R. K., and Shaffer, N. R., 1983b, Lithostratigraphy, mineralogy, and geochemistry of the New Albany Shale (Devonian and Mississippian) in southeastern Indiana–Field Trip 15, *in* Shaver, R. H., and Sunderman, J. A., eds., Field trips in midwestern geology: Geological Society of America, Indiana Geological Survey, and Indiana University Department of Geology, v. 2, p. 215-241.

Hasenmueller, N. R., and Woodard, G. S., eds., 1981, Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, 100 p.; Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, DOE/MC/05204-1128, 100 p.

Hatch, J. R., Risatti, J. B., and King, J. D., 1991, Geochemistry of Illinois Basin oils and hydrocarbon source rocks, *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 403-424.

Hook, J. W., 1974, Structure of the fault systems in the Illinois-Kentucky Fluorspar District, *in* Hutcheson, D. W., ed., A symposium on the geology of fluorspar: Kentucky Geological Survey, Series X, Special Publication 22, p. 77-86.

Howe, J. R., and Thompson, T. L., 1984, Tectonics, sedimentation, and hydrocarbon potential of the Reelfoot Rift: Oil and Gas Journal, v. 82, no. 46, p. 179-190.

Hunt, J. M., 1979, Petroleum geochemistry and geology: San Francisco, Calif., Freeman and Co., 617 p.

Hunter, C. D., and Young, D. M., 1953, Relationship of natural gas occurrence and production in eastern Kentucky (Big Sandy gas field) to joints and fractures in Devonian bituminous shale: American Association of Petroleum Geologists Bulletin, v. 37, p. 282-299.

Hutton, A. C., 1991, Classification, organic petrography, and geochemistry of oil shales, *in* Proceedings, 1990 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR 90/201, p. 163-172.

Hutton, A. C., and Cook, A. C., 1980, Influence of alginite on the reflectance of vitrinite from Joadja, NSW, and some other coals and oil shales containing alginite: Fuel, v. 59, p. 711-714.

Jillson, W. R., 1919, The oil and gas resources of Kentucky: Kentucky Department of Geology and Forestry Bulletin 1, 630 p.

Jillson, W. R., 1922, The conservation of natural gas in Kentucky: Louisville, Ky., John P. Morton and Co., 152 p.

Jillson, W. R., 1931, Natural gas in western Kentucky: Kentucky Geological Survey, Series VI, v. 38, 190 p.

Kalyoncu, R. S., Boyer, J. P., and Snyder, M. J., 1979, Characterization and analysis of Devonian shales as related to release of gaseous hydrocarbons, well P-1 Sullivan County, Indiana: Columbus, Ohio, Battelle Columbus Labs, 28 p.

Keller, S. J., 1991, Map of Indiana showing oil, gas, and products pipelines: Indiana Geological Survey Miscellaneous Map 53, scale 1:500,000.

Kelly, J., 1992, Improved techniques boost Antrim Formation wells: Northeast Oil World, v. 12, no. 9, p. 16-20.

Kentucky Department of Economic Development, 1984, Gas transmission in Kentucky: Frankfort, Kentucky Department of Economic Development, scale 1:1,169,723.

Kepferle, R. C., 1981, Correlation of Devonian shale between the Appalachian and the Illinois Basins facilitated by *Foerstia* (*Protosalvinia*), *in* Roberts, T. G., ed., Economic geology, structure, v. 2 *of* Geological Society of America Cincinnati 1981 Field Trip Guidebook: Falls Church, Va., American Geological Institute, p. 334-335.

Keroher, G. C., Bedette, B., Eggleton, J. L., Hansen, B. E., Kopf, R. W., Mann, C., Melton, W. G., Jr., Nace, H. L., Palmer, K. D., Sando, W. J., Smedley, J. E., Stock, S. W., Swift, C. S., Toulmin, M. S., and Wilson, D., 1966, Lexicon of geologic names of the United States for 1936-1960, part 2, G-O: U.S. Geological Survey Bulletin 1200, p. 1449-2886.

Keyes, C. R., 1892, Principal Mississippian section: Geological Society of America Bulletin, v. 3, p. 283-300.

Keyes, C. R., 1898, Some geological formations of the Cap-au-Grès uplift: Iowa Academy of Science Proceedings, v. 5, p. 58-63.

Keyes, C. R., 1912a, Nether delimitation of our carbonic rocks: Iowa Academy of Science Proceedings, v. 19, p. 153-156.

Keyes, C. R., 1912b, Sundry provincial and local phases of the general geologic section of Iowa: Iowa Academy of Science Proceedings, v. 19, p. 147-151.

Kingston, D. R., Dishroon, C. P., and Williams, P. A., 1983, Global basin classification system: American Association of Petroleum Geologists Bulletin, v. 67, p. 2175-2193.

Klein, G. de V., 1987, Current aspects of basin analysis: Sedimentary Geology, v. 50, p. 95-118.

Klemme, H. D., 1980, Petroleum basins–classifications and characteristics: Journal of Petroleum Geology, v. 27, p. 30-66.

Kulander, B. R., Dean, S. L., and Barton, C. C., 1977, Fractographic logging for determination of pre-core and core-induced fractures–Nicholas Combs No. 7239 well, Hazard, Kentucky: U.S. Department of Energy, MERC/CR-77/3, 44 p.

Kuuskraa, V. A., Sedwick, K. B., Thompson, K. B., and Wicks, D. E., 1985, Technically recoverable Devonian shale gas in Kentucky: U.S. Department of Energy, DOE/MC/19239-1834, 120 p.

Lancaster, D. E., 1990, Current status of stimulation research in the CSW program: Devonian Gas Shales Technology Review, v. 6, nos. 2/3, p. 7-20.

Lang, K. R., and Oliver, S. J. P., 1991, Reservoir characterization and performance in the Antrim Shale: Devonian Gas Shales Technology Review, v. 7, no. 2, p. 34-49.

Lechler, P. J., Hasenmueller, N. R., Bassett, J. L., and Leininger, R. K., 1979, Distribution and geochemical characterization of the Hannibal Member of the New Albany Shale in Indiana: Proceedings for Third Eastern Gas Shales Symposium, October 1979, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-79/6, p. 511-525.

Lechler, P. J., Leininger, R. K., Shaffer, N. R., and Ripley, E. M., 1980, Enrichment of heavy metals in the New Albany Shale, southern Indiana: Geological Society of America Abstracts with Programs, v. 12, p. 232.

Leininger, R. K., 1981, Inorganic geochemistry, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 53-61; Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 53-61.

Leung, S. S., and Sanders, T. P., 1973, A geochemical study of the New Albany Shale in Kentucky: Geological Society of America Abstracts with Programs, v. 5, p. 413.

Leventhal, J. S., and Kepferle, R. C., 1982, Geochemistry and geology of strategic metals and uranium in Devonian shales of the Eastern Interior United States, *in* Symposium Papers, Synthetic Fuels from Oil Shale, II: Nashville, Tenn., Institute of Gas Technology, p. 73-96.

Lineback, J. A., 1968, Subdivisions and depositional environments of the New Albany Shale (Devonian-Mississippian) in Indiana: American Association of Petroleum Geologist Bulletin, v. 52, p. 1291-1303.

Lineback, J. A., 1970, Stratigraphy of the New Albany Shale in Indiana: Indiana Geological Survey Bulletin 44, 73 p.

Lineback, J. A., 1980, Coordinated study of the Devonian black shale in the Illinois Basin: Illinois, Indiana, and western Kentucky: Morgantown Energy Technology Center, U.S. Department of Energy, Contract/Grant Report 1981-1, 36 p.

Lowry, P. H., Hamilton-Smith, T., Falleur, J., and Passaretti, M., 1989, Geological evaluation: Sterling Drilling and Production Co. Jarvis No. 1143, GRI Comprehensive Study Well No. 2, Calhoun County, West Virginia: Chicago, Ill., Gas Research Institute, GRI-89/0199, 31 p.

Manger, K. C., and Curtis, J. B., 1991, Geologic influences on location and production of Antrim Shale gas: Devonian Gas Shales Technology Review, v. 7, no. 2, p. 5-16.

Markowitz, G., 1979, A geochemical study of the Upper Devonian-Lower Mississippian black shales in eastern Kentucky: Lexington, University of Kentucky, M.S. thesis, 225 p.

Maslowski, A., 1991, Antrim Shale celebrates its golden anniversary: Northeast Oil World, v. 11, no. 4, p. 22-23.

Matthews, R. D., 1983, *Foerstia* from the Antrim Shale (Devonian) of Michigan: Geology, v. 11, p. 327-330.

Matthews, R. D., Humphrey, J. P., McNamara, P. H., Kinkel, C. G., and Peil, C. A., 1978, In situ processing of Michigan Antrim–field tests: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 230-239.

McGuire, D. R., and Oliver, S. J. P., 1988, Devonian shale gas production in the Michigan Basin: Eastern Gas Shales Technology Review, v. 5, nos. 2/3, p. 28-40.

Meents, W. F., 1968, Oil and gas industry in Illinois, 1968: Illinois State Geological Survey, scale 1:500,000.

Meents, W. F., and Swann, D. H., 1965, Grand Tower Limestone (Devonian) of southern Illinois: Illinois State Geological Survey Circular 389, 34 p.

Meinschein, W. G., 1981, Organic geochemistry, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 45-52; Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 45-52.

Melhorn, W. N., and Smith, N. M., 1959, The Mt. Carmel Fault and related structural features in south-central Indiana: Indiana Geological Survey Report of Progress 16, 29 p.

Miller, D. D., and Johnson, R. J. E., 1979, Acoustic and mechanic analysis of a transverse anisotropy in shale: Proceedings for Third Eastern Gas Shales Symposium, October 1979, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-79/6, p. 527-542.

Moody, J. R., Kemper, J. R., Johnston, I. M., Frankie, W. T., and Elkin, R. R., 1987a, Geologic and hydrocarbon report of Martin County: Part 4 of 5: Hydrocarbon production from the Devonian shale in Letcher, Knott, Floyd, Martin, and Pike Counties, eastern Kentucky: Kentucky Geological Survey, 22 p.

Moody, J. R., Kemper, J. R., Johnston, I. M., Frankie, W. T., and Elkin, R. R., 1987b, Geologic and hydrocarbon report of Pike County: Part 5 of 5: Hydrocarbon production from the Devonian shale in Letcher, Knott, Floyd, Martin, and Pike Counties, eastern Kentucky: Kentucky Geological Survey, 61 p.

Moore, R. C., 1928, Early Mississippian formations in Missouri: Missouri Bureau of Geology and Mines, v. 21, 283 p.

Nelson, W. J., 1991, Structural styles of the Illinois Basin, *in* Leighton, M. W., Kolata, D. R., Oltz, D. F., and Eidel, J. J., eds., Interior cratonic basins: American Association of Petroleum Geologists Memoir 51, p. 209-243.

Nelson, W. J., in preparation, Bedrock geology of the Paducah 1° *x* 2° Quadrangle: Illinois State Geological Survey Bulletin, scale 1:250,000.

Nelson, W. J., in press, Structural features in Illinois: Illinois State Geological Survey Bulletin 100.

Nelson, W. J., and Krausse, H. F., 1981, The Cottage Grove Fault System in southern Illinois: Illinois State Geological Survey Circular 522, 65 p.

Nelson, W. J., and Lumm, D. K., 1984, Structural geology of southeastern Illinois and vicinity: Illinois State Geological Survey, Contract/Grant Report 1984-2, and U.S. Nuclear Regulatory Commission NUREG/CR-4036, 127 p.

Nelson, W. J., and Lumm, D. K., 1985, The Ste. Genevieve Fault Zone, Missouri and Illinois: Illinois State Geological Survey, Contract/

Grant Report 1985-3, and U.S. Nuclear Regulatory Commission NUREG/CR 4333, 94 p.

Nelson, W. J., and Lumm, D. K., 1987, Structural geology of southeastern Illinois and vicinity: Illinois State Geological Survey Circular 538, 70 p.

Newcombe, R. B., 1932, Geology of Muskegon oil field, Muskegon, Michigan: American Association of Petroleum Geologists Bulletin, v. 16, p. 153-168.

Noger, M. C., 1982, Preliminary structure on top of the Beech Creek Limestone of the Golconda Formation, *in* Williams, D. A., Noger, M. C., and Gooding, P. J., Investigation of subsurface tar sand deposits in western Kentucky: Kentucky Geological Survey, Series 11, Information Circular 7, pl. 2, scale 1:125,000.

Norby, R. D., and Ettensohn, F. R., 1992, Stratigraphy and biostratigraphy of the New Albany Shale (Devonian-Mississippian) in the Illinois Basin: American Association of Petroleum Geologists, v. 76, p. 1282.

North, W. G., 1969, The Middle Devonian strata of southern Illinois: Illinois State Geological Survey Circular 441, 48 p.

Nuttall, B. C., 1986, Oil and gas drilling activity for Kentucky, 1985: Kentucky Geological Survey, Series 11, Information Circular 17, 271 p.

Nuttall, B. C., 1987, Oil and gas drilling activity for Kentucky, 1986: Kentucky Geological Survey, Series 11, Information Circular 24, 365 p.

Nuttall, B. C., 1988, Oil and gas drilling activity for Kentucky, 1987: Kentucky Geological Survey, Series 11, Information Circular 26, 200 p.

Nuttall, B. C., 1989a, Index to oil and gas fields of Kentucky: Kentucky Geological Survey, Series 11, Information Circular 27, 267 p.

Nuttall, B. C., 1989b, Oil and gas drilling activity for Kentucky, 1988: Kentucky Geological Survey, Series 11, Information Circular 28, 164 p.

Nuttall, B. C., 1990, Oil and gas drilling activity for Kentucky, 1989: Kentucky Geological Survey, Series 11, Information Circular 30, 180 p.

Nuttall, B. C., 1991, Oil and gas drilling activity for Kentucky, 1990: Kentucky Geological Survey, Series 11, Information Circular 35, 158 p.

Oliver, S. J. P., Coates, J.-M. P., Kuuskraa, V. A., Kelafant, J. R., and Brandenburg, C. F., 1989, The Antrim Shale of the Michigan Basin: An active Devonian shale gas play: Society of Petroleum Engineers, Gas Technology Symposium, Dallas, Tex., June 7-9, 1989, Society of Petroleum Engineers 19104, p. 487-494.

Penrose, R. A. F., Jr., 1891, Manganese: Its uses, ores, and deposits: Arkansas Geological Survey Annual Report 1890, v. 1, 642 p.

Peters, K. E., 1986, Guidelines for evaluating petroleum source rock using programmed pyrolysis: American Association of Petroleum Geologists Bulletin, v. 70, p. 318-329.

Phinney, A. J., 1890, The natural gas field of Indiana: U.S. Geological Survey Annual Report 11, pt. 1, p. 579-742.

Pickering, A., 1979, Stratigraphy and depositional environment of bone beds at the North Vernon Limestone-New Albany Shale (Devonian) contact in southeastern Indiana: Bloomington, Indiana University, M.S. thesis, 117 p.

Price, L. C., and Barker, C. E., 1985, Suppression of vitrinite reflectance in amorphous rich kerogen–A major unrecognized problem: Journal of Petroleum Geology, v. 8, p. 59-84.

Reinbold, M. L., 1978, Stratigraphic relationships of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 443-454.

Reinbold, M. L., Lineback, J. A., and Wickham, J. T., 1980, Stratigraphy, *in* Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC/12142-26, p. 19-32.

Rexroad, C. B., 1969, Conodonts from the Jacobs Chapel Bed (Mississippian) of the New Albany Shale in southern Indiana: Indiana Geological Survey Bulletin 41, 55 p.

Rexroad, C. B., and Scott, A. J., 1964, Conodont zones in the Rockford Limestone and the lower part of the New Providence Shale (Mississippian) in Indiana: Indiana Geological Survey Bulletin 30, 54 p.

Rich, J. L., 1948, Probable deep-water origin of the Marcellus-Ohio-New Albany-Chattanooga black shales [abs.]: Geological Society of America Bulletin, v. 59, p. 1346-1347.

Ripley, E. M., and Shaffer, N. R., 1989a, Organic matter of a metal-rich New Albany Shale of Indiana: Association of Organic Petrologists Abstracts, v. 6, p. 54.

Ripley, E. M., and Shaffer, N. R., 1989b, Sulfide-mineral textures in metal-rich units of the New Albany Shale, Indiana: U.S. Geological Survey Circular 1037, p. 15.

Ripley, E. M., Shaffer, N. R., and Gilstrap, M. S., 1990, Distribution and geochemical characteristics of metal enrichment in the New Albany Shale (Devonian-Mississippian), Indiana: Economic Geology, v. 85, p. 1790-1807.

Robl, T. L., Barron, L. S., Koppenaal, D. W., and Bland, A. E., 1984, The geology and geochemistry of Devonian shales in south and west central Kentucky, *in* Proceedings, 1983 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR83/089, p. 59-71.

Robl, T. L., and Koppenaal, D. W., 1982, The chemical and engineering properties of eastern oil shale, final report: Lexington, University of Kentucky Institute for Mining and Minerals Research, 288 p.

Robl, T. L., Rimmer, S. M., and Barron, L. S., 1991, Organic petrography of Mississippian and Devonian shales in east-central Kentucky, *in* Proceedings, 1990 Eastern Oil Shale Symposium: Lexington, University of Kentucky, Institute for Mining and Minerals Research, IMMR 90/201, p. 173-178.

Roen, J. B., 1984, Geology of the Devonian black shales of the Appalachian Basin: Organic Geochemistry, v. 5, no. 4, p. 241-254.

Rubey, W. W., 1952, Geology and mineral resources of the Hardin and Brussels Quadrangles (in Illinois): U.S. Geological Survey Professional Paper 218, 179 p.

Rudman, A. J., Summerson, C. H., and Hinze, W. J., 1965, Geology of basement in Midwestern United States: American Association of Petroleum Geologists Bulletin, v. 49, p. 894-904.

Sable, E. G., and Dever, G. R., Jr., 1990, Mississippian rocks in Kentucky: U.S. Geological Survey Professional Paper 1503, 125 p.

Savage, T. E., 1930, The Devonian rocks of Kentucky: Kentucky Geological Survey, Series VI, v. 33, p. 1-161.

Scheper, R. J., and Meyers, S. D., 1988, Study of Devonian shale gas geology and production in West Virginia, Kentucky, and Ohio: Journal of Petroleum Technology, v. 40, no. 6, p. 749-752.

Schettler, P. D., and Parmely, C. R., 1987a, Gas composition shifts in Devonian shales, *in* Proceedings, Society Petroleum Engineers Eastern Regional Meeting, Pittsburgh, Pa., October 21-23, 1987: Society of Petroleum Engineers, Society of Petroleum Engineers 17033, p. 53-60.

Schettler, P. D., and Parmely, C. R., 1987b, Gas storage and transport in the Devonian shales, *in* Proceedings, Society Petroleum Engineers Eastern Regional Meeting, Pittsburgh, Pa., October 21-23, 1987:

Society of Petroleum Engineers, Society of Petroleum Engineers 17070, p. 415-423.

Schettler, P. D., and Parmely, C. R., 1990, The measurement of gas desorption isotherms for Devonian shale: Devonian Gas Shales Technology Review, v. 7, no. 1, p. 4-9.

Schettler, P. D., and Parmely, C. R., 1993, Physicochemical properties of methane storage and transport in Devonian Shale-final report GRI 93/0158: Chicago, Ill., Gas Research Institute, 47 p.

Schettler, P. D., Parmely, C. R., and Wampler, D. L., 1988, Physicochemical properties of methane storage and transport in Devonian shale: Chicago, Ill., Gas Research Institute, 186 p.

Schettler, P. D., Jr., Wampler, D. L., Sipling, P. J., and Mitchell, D. J., 1977, The relationship of thermodynamic and kinetic parameters to well production in Devonian shale, *in* Enhanced oil and gas recovery and improved drilling methods: Tulsa, Okla., Energy Research and Development Administration, p. G-10/1 to G-10/12; 1978, Proceedings [for] First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 608-619.

Schoell, M., 1983, Genetic characterization of natural gases: American Association of Petroleum Geologists Bulletin, v. 67, p. 2225-2238.

Schopf, J. M., and Schwietering, J. F., 1970, The *Foerstia* Zone of the Ohio and Chattanooga Shales: U.S. Geological Survey Bulletin 1294-H, 15 p.

Schwalb, H., and Norris, R., 1980a, East-west cross sections, north and south of Rough Creek Fault System: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 900.

Schwalb, H., and Norris, R., 1980b, Isopach map of Sweetland Creek Member of New Albany Shale, western Kentucky: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 903, scale 1:500,000.

Schwalb, H., and Norris, R., 1980c, North-south cross section, east side of area: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 904.

Schwalb, H., and Norris, R., 1980d, North-south cross section, west side of area: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 901.

Schwalb, H. R., and Norris, R. L., 1980e, Occurrence of natural gas in the New Albany Shale, western Kentucky, 1980: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 906, scale 1:500,000.

Schwalb, H. R., and Norris, R. L., 1980f, Studies of New Albany Shale in western Kentucky, final report: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/METC/8215-1, 55 p.

Schwalb, H. R., and Potter, P. E., 1978, Structure and isopach map of the New Albany-Chattanooga-Ohio Shale (Devonian and Mississippian) in Kentucky: western sheet: Kentucky Geological Survey, Series X, scale 1:250,000.

Schwalb, H. R., Wilson, E. N., and Sutton, D. G., 1971, Oil and gas map of Kentucky, sheet 2, west-central part: Kentucky Geological Survey, Series X, scale 1:250,000.

Shaffer, N. R., and Branam, T. D., 1991, What is all this fuzzy stuff and what does it mean [abs.]: Indiana Academy of Science Proceedings for 1990, v. 197, p. 62.

Shaffer, N. R., and Chen, P.-Y., 1981, Mineralogy and petrography, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 34-44; Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 34-44.

Shaffer, N. R., Chou, C.-L., Frost, J. K., and Coveney, R. M., Jr., 1988, Geochemical and petrologic features of phosphate nodules in Paleozoic Midwestern black shales: Geological Society of America Abstracts with Programs, v. 20, p. 212.

Shaffer, N. R., and Leininger, R. K., 1986, Oil yields of fresh and weathered oil shales of Indiana, *in* Proceedings, 1985 Eastern Oil Shale Symposium: Lexington, University of Kentucky, Kentucky Energy Cabinet Laboratory, KECL86-147, p. 277-282.

Shaffer, N. R., Leininger, R. K., and Ennis, M. V., 1983, Comparison of organic-rich shales of Pennsylvanian age in Indiana with New Albany Shale: American Association of Petroleum Geologists Bulletin, v. 67, p. 1459-1460.

Shaffer, N. R., Leininger, R. K., and Gilstrap, M. S., 1984, Composition of the uppermost beds of the New Albany Shale in southeastern Indiana, *in* Proceedings, 1983 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR83/089, p. 195-206.

Shaffer, N. R., and Ripley, E. M., 1992, Organic geochemistry of Devonian and Pennsylvanian metalliferous black shales of Indiana: Journal of Geochemical Exploration, v. 46, p. 234-235.

Shaffer, N. R., Yates, M. G., and Ripley, E. M., 1982, Sulfur isotope ratios in pyrites from the New Albany Shale of Indiana: Geological Society of America Abstracts with Programs, v. 14, p. 287.

Shaver, R. H., (compiler), 1985, Midwestern basin and arches region, *in* Lindberg, F. A., ed., Correlation of stratigraphic units of North America: American Association of Petroleum Geologists COSUNA Chart Series, 1 sheet.

Shumaker, R. C., 1986, Structural development of Paleozoic continental basins of eastern North America, *in* Aldrich, M. J., Jr., and Laughlin, A. W., eds., Proceedings of the Sixth International Conference on Basement Tectonics, Santa Fe, N. Mex., September 16-20, 1985: Salt Lake City, Utah, International Basement Tectonics Association, p. 82-95.

Sloss, L. L., 1979, Plate-tectonic implications of the Pennsylvanian System of the Illinois Basin, *in* Palmer, J. E., and Dutcher, R. R., eds., Depositional and structural history of the Pennsylvanian System of the Illinois Basin, part 2: Illinois State Geological Survey Guidebook Series 15a, p. 107-112.

Smidchens, Z., and Boberg, W. S., in review, Map showing reported oil and gas shows from the New Albany Shale (Devonian and Mississippian) in Indiana: Indiana Geological Survey Miscellaneous Map, scale 1:500,000.

Snyder, M. J., Rausch, M. P., Ogden, J. S., and Coutant, R. W., 1978, Characterization and analysis of Devonian shales: Gas composition and release rates: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 524-545.

Soeder, D. J., 1986, Porosity and permeability of eastern Devonian gas shale, *in* Proceedings, Unconventional Gas Technology Symposium, Louisville, Ky., May 18-21, 1986: Society of Petroleum Engineers, Society of Petroleum Engineers 15213, p. 75-81.

Sorgenfrei, H., Jr., 1952, Gas production from the New Albany Shale: Bloomington, Indiana University, M.S. thesis, 26 p.

Stevenson, D. L., and Dickerson, D. R., 1969, Organic geochemistry of the New Albany Shale in Illinois: Illinois State Geological Survey Illinois Petroleum 90, 11 p.

Sullivan, D. M., in preparation, Natural gas fields in Indiana: Indiana Geological Survey Special Report.

Sullivan, D. M., Ault, C. H., and Tanner, G. F., 1982, Mt. Carmel Fault in south-central Indiana, *in* Ault, C. H., and Sullivan, D. M., eds., Faulting in southwest Indiana: U.S. Nuclear Regulatory Commission, NUREG/CR-2908, p. 34-41.

Sutton, A. H., and Wagner, O. E., Jr., 1930, Geologic map of Meade County, Kentucky: Kentucky Geological Survey, Series VI, scale 1:62,500.

Thiessen, R., 1925, Microscopic examination of Kentucky oil shales, *in* Thiessen, R., White, D., and Crouse, C. S., Oil shales of Kentucky: Kentucky Geological Survey, Series VI, v. 21, Chapter I, p. 1-47.

Thomas, J., Jr., and Frost, R. R., 1978, Internal surface area and porosity in eastern gas shales from the sorption of nitrogen, carbon dioxide, and methane–A status report: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 589-595.

Thomas, W. A., 1991, The Appalachian-Ouachita rift margin of southeastern North America: Geological Society of America Bulletin, v. 103, p. 415-431.

Tissot, B. P., Pelet, R., and Ungerer, P. H., 1987, Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation: American Association of Petroleum Geologists Bulletin, v. 71, p. 1445-1466.

Tissot, B. P., and Welte, D. H., 1984, Petroleum formation and occurrence (2nd ed.): New York, Springer-Verlag, 699 p.

Trace, R. D., 1974, Illinois-Kentucky Fluorspar District, *in* Hutcheson, D. W., ed., A symposium on the geology of fluorspar: Kentucky Geological Survey, Series X, Special Publication 22, p. 58-76.

Treworgy, J. D., 1981, Structural features in Illinois–A compendium: Illinois State Geological Survey Circular 519, 22 p.

Udden, J. A., 1899, Sweetland Creek beds: Journal of Geology, v. 7, p. 65-78.

Weller, S., 1914, Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois State Geological Survey Monograph 1, part 1, 508 p.; part 2, 187 p.

Whiting, L. L., and Stevenson, D. L., 1965, The Sangamon Arch: Illinois State Geological Survey Circular 383, 20 p.

Williams, D. A., Noger, M. C., and Gooding, P. J., 1982, Investigation of subsurface tar sand deposits in western Kentucky: Kentucky Geological Survey, Series XI, Information Circular 7, 25 p.

Williams, J. S., 1943, Stratigraphy and fauna of the Louisiana Limestone of Missouri: U.S. Geological Survey Professional Paper 203, 133 p.

Workman, L. E., and Gillette, T., 1956, Subsurface stratigraphy of the Kinderhook Series in Illinois: Illinois State Geological Survey Report of Investigations 189, 46 p.

Yost, A. B., II, 1986, Risks and rewards of well drilling in the Devonian shale: Society of Petroleum Engineers Unconventional Gas Technology Symposium, Louisville, Ky., May 18-21, 1986, Society of Petroleum Engineers 15232.

Young, D. C., 1978, Chemical and physical properties of Michigan Antrim Shale: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 129-137.

Zielinski, R. E., 1978, Geochemical characterization of Devonian gas shale: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 546-571.

Zielinski, R. E., Attalla, A., Stacy, E., Craft, B. D., and Wise, R. L., 1978, Physiochemical characterization of Devonian gas shale: Proceedings, First Eastern Gas Shales Symposium, Morgantown, W. Va., October 1977, Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 206-229.

Zielinski, R. E., and McIver, R. D., 1982, Resource and exploration assessment of the oil and gas potential in the Devonian gas shales of the Appalachian Basin: U.S. Department of Energy, MLM-MU-82-61-0002, 326 p.

Zielinski, R. E., and Moteff, J. D., 1980, Physical and chemical characterization of Devonian gas shale: Quarterly Status Report (April 1-June 30, 1980), Monsanto Research Corporation, Mound Facility, Miamisburg, Ohio, MLM-EGSP-TPR-Q-014.

Zoback, M. L., and Zoback, M. D., 1989, Tectonic stress field of the continental United States: Geological Society of America Memoir 172, p. 523-539.

APPENDIX A
Selected Bibliography

Avila, J., 1976, Devonian shale as source of gas, *in* Natural gas from unconventional sources: Washington, D. C., National Research Council, p. 73-85.

Barron, L. S., and Ettensohn, F. R., 1980, A bibliography of the paleontology and paleoecology of the Devonian-Mississippian black-shale sequence in North America: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/METC/5202-13, 86 p.

Bassett, J. L., Blakely, R. F., Carr, D. D., Hasenmueller, N. R., and Powell, R. L., 1978, Relationship of lineaments to gas production in the New Albany Shale in Indiana: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 251-263.

Bassett, J. L., and Hasenmueller, N. R., 1979, Map of Indiana showing reported oil and gas shows from the New Albany Shale: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, EGSP Series No. 803, scale 1:500,000.

Becker, L. E., 1974, Silurian and Devonian rocks in Indiana southwest of the Cincinnati Arch: Indiana Geological Survey Bulletin 50, 83 p.

Becker, L. E., and Keller, S. J., 1976, The New Albany Shale and equivalent strata in Indiana, *in* Shumaker, R. C., and Overbey, W. K., Jr., eds., Devonian shale production and potential: Proceedings of the Seventh Annual Appalachian Petroleum Geology Symposium, Morgantown, W. Va., Energy Resource and Development Administration, MERC/SP-76/2, p. 162-172.

Bell, A. H., 1935, Natural gas in Eastern Interior Coal Basin, *in* Geology of natural gas: Tulsa, Okla., American Association Petroleum Geologists, p. 813-842.

Blakely, R. F., 1981, Physical tests, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 70-84; Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 70-84.

Bland, A. E., Robl, T. L., and Koppenaal, D. W., 1982, Geochemistry of the New Albany, Ohio, and Sunbury Shales in east central Kentucky, *in* Proceedings, 1981 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR82/075, p. 183-194.

Born, K. E., 1944, The Devonian of west-central Tennessee: Illinois State Geological Survey Bulletin 68-A, p. 139-154.

Branson, E. B., 1944, Devonian of northeastern Missouri: Illinois State Geological Survey Bulletin 68-A, p. 174-181.

Campbell, G., 1956, New Albany Shale and Kinderhook Series in Indiana [abs.]: Geological Society of America Bulletin, v. 67, p. 1679.

Caylor, G. W., 1944, The Devonian of the Centralia-Salem area: Illinois State Geological Survey Bulletin 68-A, p. 200-204.

Ciccioli, P., Hayes, J. M., Rinaldi, G., Denson, K. B., and Meinschein, W. G., 1979, Graphitized carbon in gas-liquid-solid chromatography and gas chromatography/mass spectrometric analysis of high boiling hydrocarbon mixtures: Analytical Chemistry, v. 51, p. 400-408.

Cluff, R. M., and Reinbold, M. L., 1978, Anoxic conditions during New Albany Shale Group (Devonian-Mississippian) deposition in the Illinois Basin [abs.]: Geological Society of America Abstracts with Programs, v. 10, p. 249.

Collinson, C., 1961, The Kinderhookian Series in the Mississippi Valley, *in* Kansas Geological Society Guidebook, Twenty-sixth Field Conference, northeastern Missouri and west-central Illinois: Kansas Geological Society, p. 100-109.

Conkin, J. E., 1990, Pyroclastic mineral euhedral horizons in Eastern United States Devonian oil shales, *in* Proceedings, 1989 Eastern Oil Shale Symposium: Lexington, University of Kentucky, Institute for Mining and Minerals Research, IMMR89/201, p. 253-268.

Conkin, J. E., and Conkin, B. M., 1973, Middle Devonian bone beds and associated stratigraphy and fossil zones of northwestern Kentucky and southern Indiana [abs.]: Geological Society of America Abstracts with Programs, v. 5, p. 389.

Conkin, J. E., and Conkin, B. M., 1979a, Devonian pyroclastics in eastern North America, their stratigraphic relationships and correlation, *in* Conkin, J. E., and Conkin, B. M., eds., Devonian-Mississippian boundary in southern Indiana and northwestern Kentucky: Field Trip 7, Ninth International Congress of Carboniferous Stratigraphy and Geology, Louisville, Ky., University of Louisville, p. 74-141.

Conkin, J. E., and Conkin, B. M., 1979b, The Devonian-Mississippian and Kinderhookian boundaries in southern Indiana and northwestern Kentucky, *in* Conkin J. E., and Conkin, B. M., eds., Devonian-Mississippian boundary in southern Indiana and northwestern Kentucky: Field Trip 7, Ninth International Congress of Carboniferous Stratigraphy and Geology, Louisville, Ky., University of Louisville, p. 46-63.

Cooper, G. A., 1944, Remarks on correlation of Devonian formations in Illinois and adjacent states: Illinois State Geological Survey Bulletin 68-A, p. 217-222.

Cooper, G. A., Butts, C., Caster, K. E., Chadwick, G. H., Goldring, W., Kindle, E. M., Kirk, E., Merriam, C. W., Swartz, F. M., Warren, P. S., Warthin, A. S., and Willard, B., 1942, Correlation of the Devonian sedimentary formations of North America: Geological Society of America Bulletin, v. 53, p. 1729-1794.

Cooper, M., 1958, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States, pt. 5: Geological Society of America Special Paper 67, 472 p.

Croneis, C., 1944, The Devonian of southeastern Missouri: Illinois State Geological Survey Bulletin 68-A, p. 103-131.

Cross, A. T., and Hoskins, J. H., 1951, Paleobotany of Devonian-Mississippian black shales: Journal of Paleontology, v. 25, p. 713-728.

Duncan, D. C., and Swanson, V. E., 1965, Organic-rich shale of the United States and world land areas: U.S. Geological Survey Circular 523, 30 p.

Fix, C. E., 1958, Selected annotated bibliography of the geology and occurrence of uranium-bearing marine black shales in the United States: U.S. Geological Survey Bulletin 1059-F, p. 263-325.

Freeman, L. B., 1944, Devonian subsurface stratigraphy in western Kentucky: Illinois State Geological Survey Bulletin 68-A, p. 155-161.

Freeman, L. B., Branson, E. B., and Stainbrook, M. A., 1944, Discussion: Illinois State Geological Survey Bulletin 68-A, p. 214-216.

Griffith, C., 1977, Stratigraphy and paleoenvironment of the New Albany Shale (Upper Devonian) of north-central Kentucky: Madison, University of Wisconsin, M.S. thesis, 220 p.

Gruy Federal, Inc., 1976, Final report under ERDA Contract No. E-(46-1)-8061, submitted to Morgantown Energy Research Center

November 22, 1976: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, 45 p.

Hall, V. S., 1980, An eastern gas shales bibliography [and] selected annotations–Gas, oil, uranium, etc. citations in bituminous shales worldwide: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/METC/12594-12, 532 p.

Harvey, R. D., White, W. A., Cluff, R. M., Frost, J. K., and DuMontelle, P. B., 1978, Petrology of New Albany Shale Group (Upper Devonian and Kinderhookian) in the Illinois Basin, a preliminary report: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 239-265; Illinois State Geological Survey Reprint Series 1978-F.

Hasenmueller, N. R., and Bassett, J. L., 1979, Map of Indiana showing thickness of New Albany Shale (Devonian and Mississippian) and equivalent strata: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 805, scale 1:500,000.

Hasenmueller, N. R., and Bassett, J. L., 1980a, Map of Indiana showing thickness of the Blocher Member of the New Albany Shale (Devonian and Mississippian): Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 807, scale 1:500,000.

Hasenmueller, N. R., and Bassett, J. L., 1980b, Map of Indiana showing thickness of the Clegg Creek-Camp Run-Morgan Trail Members (undifferentiated) of the New Albany Shale (Devonian and Mississippian): Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 809, scale 1:500,000.

Hasenmueller, N. R., and Bassett, J. L., 1980c, Map of Indiana showing the thickness of the Selmier Member of the New Albany Shale (Devonian and Mississippian): Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 808, scale 1:500,000.

Hasenmueller, N. R., and Bassett, J. L., 1980d, Stratigraphic cross sections showing members of the New Albany Shale (Devonian and Mississippian) in Indiana: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 816, scale 1:500,000.

Hasenmueller, N. R., and Bassett, J. L., 1981, Structure, *in* Hasenmueller, N. R., and Woodard, G. S., eds., Studies of the New Albany Shale (Devonian and Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, p. 33; Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, DOE/MC/05204-1128, p. 33.

Henderson, J. R., Jr., and Zietz, I., 1958, Interpretation of an aeromagnetic survey of Indiana: U.S. Geological Survey Professional Paper 316-B, p. 19-37.

Huddle, J. W., 1934, Conodonts from the New Albany Shale of Indiana: Bulletins American Paleontology, v. 21, no. 72, 136 p.; Bloomington, Indiana University, Ph.D. dissertation, 196 p.

Hunt, C. B., 1974, Natural regions of the United States and Canada (3rd ed.): San Francisco, Calif., W. H. Freeman, 725 p.

Illinois State Geological Survey, 1980, Geologic and geochemical studies of the New Albany Group (Devonian black shale) in Illinois to evaluate its characteristics as a source of hydrocarbons, *in* Manilla, R. D., ed., Semi-Annual Report for the Unconventional Gas Recovery Program: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy DOE/METC/SP-80/22, p. 3-26–3-33.

Kalyoncu, R. S., Coppins, W. G., Hooie, D. T., and Snyder, M. J., 1978, Characterization and analysis of Devonian shales: 1. Physical characterization: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 230-258.

Kaplan, I. R., 1983, Stable isotopes of sulfur, nitrogen and deuterium in recent marine environments, *in* Stable Isotopes in Sedimentary Geology: Society of Economic Paleontologists and Mineralogists Short Course No. 10, Dallas, Tex., 1983, Chapter 2, 108 p.

Kepferle, R. C., 1974, Geologic map of parts of the Louisville West and Lanesville Quadrangles, Jefferson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1202, scale 1:24,000.

Leventhal, J. S., 1980, Comparative geochemistry of Devonian shale cores from the Appalachian Basin, Mason, Monongalia, and Upshur Counties, West Virginia; Illinois Basin, Tazewell County, Illinois, and Clark County, Indiana; and Michigan Basin, Sanilac County, Michigan: U.S. Geological Survey Open-File Report 80-938, 36 p.

Lewis, W. E., and Tandanand, S., eds., 1974, Bureau of Mines test procedure for rocks: U.S. Bureau Mines Circular 8628, 223 p.

Lineback, J. A., 1964, Stratigraphy and depositional environment of the New Albany Shale (Upper Devonian and Lower Mississippian) in Indiana: Bloomington, Indiana University, Ph.D. dissertation, 136 p.; 1965, [abs.] Dissertation Abstracts, v. 25, p. 6538.

Lineback, J. A., 1966, Deep-water sediments adjacent to the Borden Siltstone (Mississippian) delta in southern Illinois: Illinois State Geological Survey Circular 401, 48 p.

Maliva, R. G., 1984, Paleoecology and sedimentology of the Rockford Limestone and upper New Albany Shale (Lower Mississippian) in southern Indiana: Bloomington, Indiana University, M.A. thesis, 185 p.

Mehl, M. G., 1960, Relationships of the base of the Mississippian System in Missouri: Denison University Journal of the Scientific Laboratories, v. 45, p. 57-107.

Miller, D., Bauer, R. A., and Johnson, R., 1980, Physical properties, *in* Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U.S. Department of Energy, DOE/METC 12142-26, p. 77-94.

Nance, S. W., and Zielinski, R. E., [1979?], A current assessment of the physiochemical characterization data for the eastern gas shales: Miamisburg, Ohio, Monsanto Research Corporation, Mound Facility, 22 p.

Nevers, G. M., and Walker, R. D., 1962, Annotated bibliography of Indiana geology through 1955: Indiana Geological Survey Bulletin 24, 486 p.

Newcombe, R. B., 1933, Oil and gas fields in Michigan, a discussion of depositional and structural features of the Michigan Basin: Michigan Geological Survey Publication 38, Geology Series 32, 293 p.

Noel, J. A., 1979, The Plummer Field, Greene County, Indiana: Indiana Geological Survey Special Report 17, 24 p.

Patton, J. B., 1955, Underground storage of liquid hydrocarbons in Indiana: Indiana Geological Survey Report of Progress 9, 19 p.

Patton, J. B., 1977, Carbonaceous shales of Indiana as sources of energy, petrochemicals, and ceramic materials: First annual progress report: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 545-551.

Powell, R. L., 1978, Preparation of lineament maps of southwestern Indiana: U.S. of Department Energy, METC/UGS 122, 10 p.

Rinaldi, G., Ciccioli, P., Wimberg, W. B., and Meinschein, W. G., 1977, Gas chromatographic analysis of Fischer retort products of the New Albany Shale: Proceedings, First Eastern Gas Shales Symposium, October 1977, Morgantown, W. Va., Morgantown Energy Research Center, U.S. Department of Energy, MERC/SP-77/5, p. 734-747.

Schemehorn, N. R., 1956, Sedimentation study of New Albany Shale, Rockford Limestone, and New Providence Shale in Indiana: Bloomington, Indiana University, M.A. thesis, 39 p.

Schmoker, J. W., 1981, Determination of organic-matter content of Appalachian Devonian shales from gamma-ray logs: American Association of Petroleum Geologists Bulletin, v. 65, p. 1285-1298.

Schwalb, H. R., and Norris, R. L., 1980a, Isopach map of Blocher Member of New Albany Shale, western Kentucky: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 902, scale 1:500,000.

Schwalb, H., and Norris, R., 1980b, Isopach map of Grassy Creek Member of New Albany Shale, western Kentucky: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/EGSP Series No. 905, scale 1:500,000.

Scott, A. J., and Collinson, C., 1961, Conodont faunas from the Louisiana and McCraney formations of Illinois, Iowa, and Missouri, *in* Kansas Geological Society Guidebook, Twenty-sixth Annual Field Conference, northeastern Missouri and west-central Illinois: Wichita, Kansas Geological Society, p. 110-141.

Shaffer, N. R., Bassett, J. L., Carr, D. D., Chen, P.-Y., Hasenmueller, N. R., Lechler, P. J., and Leininger, R. K., 1978, Comparison of the New Albany Shale from deep and shallow parts of the Illinois Basin in Indiana: Preprints for Second Eastern Gas Shales Symposium, October 1978, Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 1, p. 219-229.

Shaver, R. H., Ault, C. H., Burger, A. M., Carr, D. D., Droste, J. B., Eggert, D. L., Gray, H. H., Harper, D., Hasenmueller, N. R., Hasenmueller, W. A., Horowitz, A. S., Hutchison, H. C., Keith, B. D., Keller, S. J., Patton, J. B., Rexroad, C. B., and Weir, C. E., 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana–A revision: Indiana Geological Survey Bulletin 59, 203 p.

Sloss, L. L., Dapples, E. C., and Krumbein, W. C., 1960, Lithofacies maps, an atlas of the United States and southern Canada: New York, John Wiley and Sons, Inc., 108 p.

Smidchens, Z., and Boberg, W. S., in review, Map showing locations of cores of the New Albany Shale (Devonian and Mississippian) in Indiana: Indiana Geological Survey Miscellaneous Map, scale 1:500,000.

Sorgenfrei, H., Jr., 1957, Gas production from the New Albany: Compass, v. 34, p. 228-245.

Stainbrook, M. A., 1944, The Devonian System in Iowa: Illinois State Geological Survey Bulletin 68-A, p. 182-188.

Stevenson, D. L., and Whiting, L. L., 1967, Geologic structure of the Devonian-Silurian Hunton Limestone Megagroup in Illinois: Illinois State Geological Survey Illinois Petroleum 87, 5 p.

Sutton, A. H., 1944, The Devonian System in Indiana: Illinois State Geological Survey Bulletin 68-A, p. 162-173.

Tetra Tech, Inc., 1981, Evaluation of Devonian shale potential in the Illinois Basin: Morgantown, W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, DOE/METC-124, 23 p.

Thiessen, R., White, D., and Crouse, C. S., 1925, Oil shales of Kentucky: Kentucky Geological Survey, Series VI, v. 21, 242 p.

Thompson, J. A., Rimmer, S. M., and Robl, T. L., 1992, Organic facies in Devonian shales of east-central Kentucky: Preliminary results *in* Proceedings, 1991 Eastern Oil Shale Symposium: Lexington, University of Kentucky Institute for Mining and Minerals Research, IMMR91/07, p. 405-414.

Tourtelot, E. B., 1970, Selected annotated bibliography of minor-element content of marine black shales and related sedimentary rocks, 1930-65: U.S. Geological Survey Bulletin 1293, 118 p.

Van Dyke, L. H., Hoeflinger, J. P., and Brigham, W. D., 1980, Geologic and geochemical studies of the New Albany Shale Group (Devonian and Mississippian) in Illinois, supplement I, users manual for a Mineral Resources Evaluation System (MINERS): Illinois State Geological Survey Final Report to U.S. Department of Energy, Contract DE-AC21-76ET12142, 178 p.

Vine, J. D., and Tourtelot, E. B., 1970, Geochemistry of black shale deposits–A summary report: Economic Geology, v. 65, p. 253-272.

Weller, J. M., 1944a, Devonian correlations in Illinois and surrounding states: A summary: Illinois State Geological Survey Bulletin 68-A, p. 205-213.

Weller, J. M., 1944b, Devonian System in southern Illinois: Illinois State Geological Survey Bulletin 68-A, p. 89-102.

Wimberg, W. B., 1979, Analyses of liquid and gaseous hydrocarbons present in the New Albany Shale: Bloomington, Indiana University, M.A. thesis, 74 p.

Workman, L. E., 1944, Subsurface Geology of the Devonian in Illinois: Illinois State Geological Survey Bulletin 68-A, p. 189-199.

Zielinski, R. E., and Nance, S. W., 1979, Physical and chemical characterization of Devonian gas shale: Quarterly Status Report (April 1-June 30, 1979), Monsanto Research Corporation, Mound Facility, Miamisburg, Ohio.

Zielinski, R. E., Nance, S. W., Seabaugh, P. W., and Larson, R. J., 1978, Characterization and resource assessment of the Devonian shales in the Appalachian and Illinois Basin [sic]: Preprints for Second Eastern Gas Shale Symposium, October 1978, Morgantown W. Va., Morgantown Energy Technology Center, U.S. Department of Energy, METC/SP-78/6, v. 2, p. 15-45.

APPENDIX B

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS* Interval (Feet)
		ILLINOIS STATE GEOLOGICAL SURVEY				
C28	Miller No. 1 Sample	Sangamon	11-15N-3W	595.8	632-2732	1569.4-1777
C52	Benedum Trees No. 1 Van Zant	Fayette	24-6N-1W		1587-2959	
C2651	Peoples Gas Light & Coke No. 1 Lamb	DeWitt	1-20N-4E			
C2740	Superior Oil No. C-17 Ford	White	27-4S-14W		3052-7684	
C2745	Midland Electric Coal No. 1 Peters	Peoria	11-7N-6E	622	401-1202.9	516-744
C2759	Sun Oil No. 1 Damery	Macon	5-15N-1E			
C2913	Coral Oil No. 1 Schroeder	St. Clair	6-3S-6W		1764-1814	
C3750	Maryland Service Co. No. S-1 Kircheis	Madison	27-3N-6W			
C3905	Union Hill Gas Storage No. 1 Powers	Edgar	27-15N-14W			
C4831	Texaco No. 1 Johnson	Marion	6-1N-2E			
C6652	Getty Oil No. 21 Shoulders	Crawford	20-5N-11W			
C7604	New Jersey Zinc No. J-16 Gumm	Knox	31-11N-2E			
C7864	New Jersey Zinc No. H-23 Williams	Fulton	13-8N-2E			
C13039	Rector & Stone No. 1 Missouri (MO) Portland Cement	Hardin	36-11S-7E	578	0-254.8	0-261.1?
C13040	Tri Star Prod. No. 1-D Lancaster	Effingham	31-9N-4E	612.1	3006-3107	3009.9-3100.3
C13041	Northern Illinois Gas No. 1 RAR	Henderson	32-8N-4W	772	319-566.3	319-603.7
C13042	Peoples Gas No. 1 Witt	Edgar	19-16N-13W		656-664	
C13043	Jenkins No. 1 Simpson	Wayne	17-3S-8E	387	5010-5285	5041.4-5275.1
C13044	Northern Illinois Gas No. 1 MAK	Tazewell	8-23N-2W	641	898-1158	925.1-1146.1
C13424	Helm Petroleum No. 1 Ballance	Fayette	12-4N-1W		2890-2895.4	

*NAS = New Albany Shale.

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
		INDIANA GEOLOGICAL SURVEY[†]				
5	Elm Oil & Gas Co. No. 2 Gard	Vigo	24-12N-8W	595	1595-1691[‡]	1496-1598
6	Gilliam Drlg. Co. No. 1 Swadener	Vigo	35-10N-8W	596	1057-1917	1814-1904
7	Cook No. 1 Acree & Strachan	Clay	30-12N-7W	620	1571-1591	1469-1573
14	Schwartz et al. No. 1 Everhart	Owen	21-9N-5W	670	217-2579	1345-1445
32	Gilliam Drlg. Co. No. 1 Singhurse	Vigo	20-10N-8W	612	1875-1905	1770-1874
36	Burrage No. 1 Harris	Clay	20-10N-7W	579	1684-1721	1580-1688
77	Riggs & Dice No. 1 Perigo	Fountain	4-18N-8W	633	938-1148	816-940
99	Thompson No. 1-A Stoner	Montgomery	15-17N-3W	891	715-848	599-725
100	Thompson No. 1-D Randall	Boone	26-19N-2W	909	462-573	375-471
102	Indiana Gas & Water Co. No. 1 Robertson	Monroe	9-9N-1E	833	816-963	694-817
107	IGS SDH[§] No. 9 Hawkins	Benton	6-25N-9W	714	48-267	254-267+
108	IGS SDH No. 10 Indiana Highway Dept.	Newton	31-27N-9W	695	54-61	58-61+
125	IGS SDH No. 20 Oliver	Johnson	17-11N-5E	671	61-409	61-121
128	IGS SDH No. 21 Meshberger Stone Co.	Bartholomew	5-8N-7E	691	20-295	17-22
131	IGS SDH No. 24 Vance	Jennings	4-5N-8E	672	23-200	23-24
161	Texas Eastern Trans. Corp. No. 1 Texas Eastern Trans. Corp.	Jackson	27-7N-6E	650	66-503	66-107
170	IGS SDH No. 51	Jasper	22-28N-6W	674	26.9-107	26.9-27
171	IGS SDH No. 52	Jasper	21-28N-6W	672	30-156	30-105
174	IGS SDH No. 55 Carpenter	Jackson	36-7N-5E	630	46-98	82-98+
188	IGS SDH No. 64 Indiana University	Monroe	33-9N-1W	791	8-960	773-891
196	IGS SDH No. 70 Louisville Cement Co.	Clark	146 CMG[‖]-1S-6E	527	7-191	70-179
226	IGS SDH No. 80 Strassberger	Benton	14-26N-9W	743	12-841	142-288
243	IGS SDH No. 100 Budde	Jasper	26-27N-7W	720	10-149	10-140
251	IGS SDH No. 110 McKee	Newton	30-27N-8W	702	125-240	125-230
253	IGS SDH No. 111-B Dietrich	Newton	31-27N-8W	697	26-392	203-353

[†] Cores processed through July 1991.

[‡] Footages are from Indiana Geological Survey core index cards.

[§] SDH = Indiana Geological Survey drill hole.

[‖] CMG = Clark Military Grant.

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
		INDIANA GEOLOGICAL SURVEY – Continued				
310	Teegarden No. 1 Teegarden	Hamilton	7-17N-3E	888	181-384	181-191
330	IGS SDH No. 147 Dieterlen	Clark	246 CMG-2N-8E	674	33-350	31-120
336	IGS SDH No. 156 Hydraulic Press Brick Co.	Morgan	36-13N-1E	622	20-340	313-340+
358	Tudor Research No. C-18 Kentland	Newton	23-27N-9W	681	82-85	79-85+
368	Tudor Research No. C-34 Kentland	Newton	25-27N-9W	707	42-45	35?-45+
375	Tudor Research No. C-50 Kentland	Newton	24-27N-9W	681	132-135	80-135+
384	Tudor Research No. S-16 Kentland	Newton	23-27N-9W	684	75-87	72-87+
385	Tudor Research No. S-17 Kentland	Newton	23-27N-9W	685	75-87	73-87+
390	Tudor Research No. S-23 Kentland	Newton	19-27N-8W	685	44-45	20-45+
391	Tudor Research No. S-24 Kentland	Newton	19-27N-8W	686	33-41	27-41+
406	Tudor Research No. S-79 Kentland	Newton	26-27N-9W	688	86-90	75-90+
428	IGS SDH No. 180 Rothrock	Harrison	30-3S-3E	452	32-800	791-800+
432	IGS SDH No. 181 Deaton	Harrison	35-1S-2E	560	40-860	841-860+
439	IGS SDH No. 184-A Kamer	Floyd	26-1S-6E	598	10-190	179-190+
440	Indiana Gas & Water Co. No. 1 Bahler	Jasper	33-27N-6W	740	45-1077	45-168
441	IGS SDH No. 185-A Staples	Clark	234 CMG-1N-6E	585	10-280	139-253
447	Indiana Gas & Water Co. No. 1 Forbes	White	3-27N-6W	703	32-1470	21-133
449	Indiana Gas & Water Co. No. 56 Banes	Fountain	16 Bur. Res.[*]-22N-6W	505	53-263	120-216
450	Indiana Gas & Water Co. No. 6 Buck & Buck	Tippecanoe	24-22N-6W	642	359-501	255-370
462	Fenix & Scisson No. 2 Shell Oil Co.	Marion	13-17N-2E	890	179-589	171-206
463	IGS SDH No. 193 Armstrong	Lawrence	28-6N-2W	591	80-1050	928-1042
472	IGS SDH No. 196 Salem Valley Farms	Boone	5-17N-2E	885	200-640	112-216
474	IGS SDH No. 199 Ohio & Indiana Stone Co.	Putnam	1-12N-4W	826	20-1060	1034-1060+
494	Mobile Drlg. Co. No. 1 Mobile Drlg. Co.	Marion	25-15N-3E	737	139-1545	139-152
507	IGS SDH No. 224 Russellville Stone Co.	Putnam	8-16N-5W	749	4-815	806-815+
515	IGS SDH No. 241 Moneto Church Camp	Brown	24-9N-3E	700	8-400	263-384
539	Texas Eastern Trans. Corp. No. 7 Texas Eastern Trans. Corp.	Jackson	27-7N-6E	639	35-496	35-107
548	Texas Gas Trans. Corp. No. 4 Peterson et al.	Sullivan	30-9N-8W	501	1873-1986	1770-1878
549	Texas Gas Trans. Corp. No. 5 Pittman	Sullivan	30-9N-8W	541	1912-2050	1812-1918

[*] Bur. Res. = Burnett's Reserve.

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
	INDIANA GEOLOGICAL SURVEY – Continued					
550	Texas Gas Trans. Corp. No. 6 Wallace	Sullivan	30-9N-8W	504	1885-2025	1794-1893
554	Energy Resources of Indiana No. 1 Phegley Farms Inc.	Sullivan	14-6N-10W	430	2490-2755	2504-2630
557	IGS SDH No. 273 Indianapolis Intl. Airport	Marion	27-15N-2E	798	190-410	223-346
558	IGS SDH No. 274 Indianapolis Intl. Airport	Marion	25-15N-2E	755	152-170	152-170+
559	IGS SDH No. 275 Indianapolis Intl. Airport	Marion	25-15N-2E	752	140-270	148-267
577	IGS SDH No. 290 Clark County State Forest	Clark	283 CMG-2N-7E	622	124-242	127-241
578	IGS SDH No. 291 Schepman	Jackson	27-6N-5E	613	173-310	173-303
580	Thomas No. 1 Mull	Jennings	1-5N-7E	669	23-64	24-55
581	Thomas No. 1 Kent	Jennings	23-6N-7E	639	33-104	34-93
583	Citizens Gas & Coke Utility No. 1 Dennis	Greene	6-8N-5W	542	1327-1368	1300-1379+
586	Thomas No. __ Thomas	Jennings	32-6N-8E	702	18-74	18-68
593	IGS SDH No. 304 Woodruff	Scott	22-3N-6E	591	125-300	164-286
594	IGS SDH No. 305 Nehrt	Jackson	9-4N-6E	562	63-220	85-206
599	Nye Metals Inc. No. 1 Carter	Hendricks	21-14N-2W	790	666-763	667-762+
606	Southern Indiana Oil Shale No. 1 Roach	Clark	241 CMG-1N-7E	613	27-153	28-143
607	Southern Indiana Oil Shale No. 1 Bowell	Clark	260 CMG-2N-7E	695	55-187	65-181
608	Southern Indiana Oil Shale No. 1 McRae	Clark	286 CMG-2N-7E	559	9-138	12-128
611	IGS SDH No. 308 Knear	Harrison	3-6S-5E	442	200-350	228-317
612	IGS SDH No. 309 Eve	Floyd	16-3S-6E	449	50-170	62-165
614	Panhandle Eastern Pipe Line Co. No. 1-7 Stewart Estate	Clay	7-13N-6W	677	1235-1394	1130-1239
616	Panhandle Eastern Pipe Line Co. No. 1-4 Marks et al.	Clay	4-13N-6W	697	1215-1342	1111-1219
618	Anschutz Corp. No. 16-19 Voelkel	Dubois	19-2S-5W	442	2080-2110	2078-2250
628	IGS SDH No. 314 Maxwell	Morgan	25-11N-1W	643	500-520	503-520+
633	Citizen Gas & Coke Utility No. 1 Benham et al.	Greene	5-6N-5W	520	1450-1511	1426-1534
634	IGS SDH No. 315 McDaniel	Morgan	26-11N-1W	626	450-630	489-621
639	IGS SDH No. 319 Piercefield	Bartholomew	8-8N-5E	644	60-240	92-225
649	IGS SDH No. 324 Speaker	Bartholomew	10-7N-5E	632	43-190	46-188

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
	INDIANA GEOLOGICAL SURVEY – Continued					
655	United States Steel Corp. No. IN-3 Annis	Jasper	24-27N-7W	726	0-277	46-126
657	United States Steel Corp. No. IN-51 Keeseling Agreement	White	27-26N-5W	730	0-366	113-242
664	Ernst No. 2 Sticklers	Clay	10-9N-6W	624	1502-1538	1400-1510?
665	IGS SDH No. 328 Nixon	Fountain	16-19N-6W	744	79-800	669-780
670	IGS SDH No. 329 Compton	Johnson	3-11N-4E	748	117-280	121-259
674	IGS SDH No. 331 Dillman	Warren	29-23N-8W	681	34-562	498-562+
679	United States Steel Corp. No. IN-48 Knochel	Jasper	28-27N-7W	750	0-386	86-244
683	Zupan Oil & Drlg. Co. No. 1 Everitt	Washington	26-4N-5E	519	130-264	161-264+
684	North Am. Explor. Inc. No. INFL-5 Von Allen	Floyd	28-1S-6E	812	425-536	427-535
685	North Am. Explor. Inc. No. INFL-3 Sperzel	Floyd	19-2S-6E	838	500-613	500-609
687	United States Steel Corp. No. IN-43 Loveless	Jasper	18-27N-6W	722	0-286	0-149
700	North Am. Explor. Inc. No. INFL-1 Summers	Floyd	1-4S-5E	450	144-246	144-244
703	Buttercup Energy Ltd. No. 1 Floyd	Greene	35-7N-5W	491	1448-2492	1341-1455
704	Buttercup Energy Ltd. No. 1 Mellis	Greene	34-7N-5W	576	1568-2620	1466-1580
706	Buttercup Energy Ltd. No. 1 Neidigh	Greene	13-7N-5W	649	1555-2618	1441-1556
713	North Am. Explor. Inc. No. INJK-10 Densford	Jackson	31-4N-6E	551	112-242	116-240
714	Eastern Shale Research No. 1 Miller	Scott	3-2N-7E	612	20-53	22-53+
718	IGS SDH No. 349 Kirkpatrick	Fountain	14-20N-7W	674	12-665	550-654
719	IGS SDH No. 350 Roe	Benton	6-24N-8W	791	64-425	268-390
722	Texas Gas Trans. Corp. No. 1-2790 Turner, Price, & Hayward	Clay	12-12N-7W	636	1369-1500	1250-1355
723	Texas Gas Trans. Corp. No. 3 Peterson et al.	Sullivan	30-9N-8W	527	1907-2082	1804-1910
725	Texas Gas Trans. Corp. No. 2936 Dewlen	Vigo	27-11N-10W	451	2036-2084	1933-2039
729	IGS SDH No. 360 McRae	Clark	286 CMG-2N-7E	553	8-31	8-31+
747	North Am. Explor. Inc. No. INBW-11 Rogers	Bartholomew	4-9N-5E	685	72-202	72-193
748	North Am. Explor. Inc. No. INBW-12 Birdwell	Bartholomew	7-8N-5E	678	114-279	136-268
749	North Am. Explor. Inc. No. INJK-12 Claycamp	Jackson	29-7N-5E	620	158-300	159-293
750	North Am. Explor. Inc. No. INBW-15 Plumlee	Bartholomew	28-10N-5E	727	108-235	107-224
751	North Am. Explor. Inc. No. INJK-13 Thompson	Jackson	9-6N-5E	562	113-273	126-259
753	North Am. Explor. Inc. No. INNW-1 Winger	Newton	36-27N-8W	739	60-199	62-225

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
	INDIANA GEOLOGICAL SURVEY – Continued					
755	North Am. Explor. Inc. No. INNW-3 Cobb	Newton	31-27N-9W	706	42-224	52-205
756	North Am. Explor. Inc. No. INJK-17 Schneck et al.	Jackson	12-6N-5E	560	94-230	95-217
758	North Am. Explor. Inc. No. INNW-2 Stevens	Newton	35-27N-9W	717	200-300	149-330
762	North Am. Explor. Inc. No. INBW-7 Peters	Bartholomew	10-7N-5E	618	30-210	50-196
763	North Am. Explor. Inc. No. INBW-10 Horne	Bartholomew	8-7N-5E	650	96-278	121-260
764	North Am. Explor. Inc. No. INBT-2 Stover	Benton	10-25N-7W	753	52-155	55-182
765	North Am. Explor. Inc. No. INJO-1 Hamilton	Johnson	10-11N-4E	760	143-319	169-303
766	North Am. Explor. Inc. No. INJK-27 Sunderman	Jackson	16-5N-6E	535	52-180	53-174
768	North Am. Explor. Inc. No. INBW-3 Day	Bartholomew	29-8N-5E	655	41-254	99-240
769	North Am. Explor. Inc. No. INBT-1 Graf	Benton	6-26N-6W	738	58-158	27-181
770	North Am. Explor. Inc. No. INJO-5 Deer	Johnson	17-12N-4E	767	150-318	167-307
775	North Am. Explor. Inc. No. INJK-1 Donahue	Jackson	4-4N-6E	550	59-185	60-185
776	United States Steel Corp. No. IN-12 Wood	White	7-27N-5W	696	0-216	9-97
783	North Am. Explor. Inc. No. INCL-8 Broady	Clark	220 CMG-1N-7E	495	13-123	7-122
784	North Am. Explor. Inc. No. INSC-6 Garriott	Scott	17-2N-7E	594	85-226	103-220
785	North Am. Explor. Inc. No. INJK-4 Hildreth	Jackson	22-5N-6E	550	53-161	53-166
786	St. Joseph Lead Co. No. 77 IN-3 Bahler	White	10-26N-6W	728	29-305	29-105
787	St. Joseph Lead Co. No. 77 IN-4 Getz	White	10-26N-6W	731	22-328	22-99
789	St. Joseph Lead Co. No. 77 IN-5 Bahler	White	15-26N-6W	731	55-353	55-132
791	St. Joseph Lead Co. No. 77 IN-2 Bahler	White	10-26N-6W	728	33-302	34-105
792	St. Joseph Lead Co. No. 77 IN-1 Bahler	White	10-26N-6W	728	27-385	27-106
798	North Am. Explor. Inc. No. INJK-7 City of Seymour	Jackson	18-6N-6E	582	92-199	92-195
811	Fenix & Scisson Inc. No. 1 Indiana Gas Co.	Boone	1-18N-1W	944	232-589	335-438

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
	KENTUCKY GEOLOGICAL SURVEY (KGS) AND KENTUCKY CENTER FOR APPLIED ENERGY RESEARCH (KCAER)					
A-5	KCERL A-5	Marion	18-M-52	810	7-57	
A-6	KCERL A-6	Marion	13-L-51	738	10-65	
A-7	KCERL A-7	Marion	19-M-50	655	11-65	
A-8	KCERL A-8	Nelson	10-O-47	590	21-73	
A-9	KCERL A-9	Nelson	25-O-49	685	11-71	
A-10	KCERL A-10	Nelson	17-N-48	586	9-66	
A-11	KCERL A-11	Nelson	9-O-47	545	14-84	
A-12	KCERL A-12	Bullitt	2-P-46	600	61-127	
A-13	KCERL A-13	Hardin	11-P-45	478	64-144	
B-3	KCERL B-3	Marion	3-L-52	710	18-75	
B-4	KCERL B-4	Marion	14-M-51	715	10-75	
B-5	KCERL B-5	Marion	13-N-49	660	15-87	
B-6	KCERL B-6	Marion	14-M-49	585	16-80	
BL11	KCERL BL11	Bullitt	20-Q-45			
C-116	KGS/USGS No. 1 Stewart	Simpson	4-C-36	706	15-648	589-643
C-117	KGS/USGS No. 1 Summit	Hardin	6-M-42	740	0-1204	1084-1160
C-120	KGS/USGS No. 1 Scott	Meade	9-Q-40	796	0-1337	924-1066
C-123B	Blankenship No. 1 Pardue	Allen	11-C-40	870	28-370	223-262
C-171	Callahan No. 1 Target	Crittenden	20-K-16	554	12-1937	1306-1608
C-173	KGS/USGS No. 1 Brown	Logan	1-C-31	570	40-893	?-893+
C-216	KGS/USGS No. 1 Canton	Trigg	9-D-19	410	0-803	760-803+
C-276	Exxon Du-2	Adair	24-I-54	863	20-2274	35-68
C-389	KGS Norm No. 1 Knievim	Bullitt	3-S-46	598	15-122	30-122
C-390	KGS Norm 2	Nelson	14-M-48	605	15-91	32-83
C-472	Blankenship No. 1 Carver	Allen	16-C-41	840	24-312	
C-479	KGS Norm 4	Nelson	21-P-46	530	15-110	35-100
C-480	KGS Norm 5	Marion	13-M-51	725	15-69	15-66
C-507	Callahan No. 3 Target	Crittenden	20-K-16	465	2-1535	1442-1483
C-508	Callahan No. 4 Target	Crittenden	20-K-16	524	24-1696	1259-1660
C-1230	Orbit Gas No. 1 Clark	Christian	12-G-25	548	2178-2328	2178-2322
L-7	KCERL L-7	Adair	2-I-52	720	10-70	21-52
L-8	KCERL L-8	Adair	20-I-53	779	14-85	25-66
L-9	KCERL L-9	Adair	12-F-51	642	9-70	14-53

APPENDIX B — Continued

Locations of cores of the New Albany Shale in the Illinois Basin on file at the Illinois State Geological Survey, Indiana Geological Survey, Kentucky Geological Survey, and Kentucky Center for Applied Energy Research. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky.

Core or File No.	Well Name (Operator, Farm)	County	Location	Surface Elevation (Feet)	Cored Interval (Feet)	NAS Interval (Feet)
KENTUCKY GEOLOGICAL SURVEY (KGS) AND KENTUCKY CENTER FOR APPLIED ENERGY RESEARCH (KCAER) – Continued						
L-10	KCERL L-10	Cumberland	5-D-51			
L-11	KCERL L-11	Cumberland	25-D-50			
L-12	KCERL L-12	Cumberland	18-E-49			
L-13	KCERL L-13	Allen	6-D-42			
L-14	KCERL L-14	Allen	23-C-40			
L-15	KCERL L-15	Allen	18-C-42			
L-16	KCERL L-16	Monroe	3-B-44	642	14-60	15-46
L-17	KCERL L-17	Monroe	6-C-48	808	12-86	42-66
MR11	KCERL MR11	Marion	4-L-51			
S2835	Sun No. 3 Robertson	Union	22-O-18	390	4464-4567	4145-4537
S3062	Yandell No. 1 Carr	Trigg	16-C-20	361	36-951	?-568
T-6	KCERL T-6	Taylor	10-K-52	775	14-82	18-65
T-7	KCERL T-7	Marion	24-M-54	935	15-84	17-66
T-8	KCERL T-8	Marion	16-M-50	630	5-75	7-57
T-9	KCERL T-9	Nelson	17-O-48	592	7-94	

APPENDIX C

Mean random vitrinite reflectance ($\bar{R}_o$) data for the New Albany Shale in the Illinois Basin.*

County	Location	Well ID	Well Name	Sample Number	$\bar{R}_o$
Illinois					
Bond	12-5N-4W	484	Texas Co. No. 1 Sybert	NAS-293	0.52
Champaign	12-22N-11E	1424	Peoples Gas No. 1 Condit	NAS-137	0.45
Champaign	33-17N-9E	307	Douglas Oil & Gas No. 1 Bozdeck	NAS-295	0.54
Champaign	23-19N-10E	132	Peoples Gas No. 1 Tracy	NAS-297	0.49
Champaign	19-19N-8E	630	Vickery Drilling Co. B-0-1	NAS-302	0.50
Christian	28-13N-1W	2375	Union Oil No. 1 Cleveland	NAS-085, 087	0.53
Christian	25-11N-1E	22776	Franks Petroleum No. 1 Wagner	NAS-140	0.52
Clark	4-10N-11W	23824	Corley No. 1 Miller	NAS-148	0.54
Clark	33-11N-14W	1492	Fanchot No. A-1 Elliott	NAS-305	0.51
Clay	11-2N-5E	1447	Keystone Oil No. 1 Woomer-Campbell	NAS-143,146	0.58
Clay	16-3N-6E	5036	Southern Illinois Oil No. 1 Mearns	NAS-028	0.49
Clay	16-3N-5E	5028	Southern Illinois Oil No. 1 Fatheree	NAS-308	0.50
Clinton	6-2N-4W	4018	Anschutz No. 1 Schroder	NAS-442	0.54
Clinton	33-3N-1W	24548	Brehm No. 1 Hemminghaus	DWS-501, 502	0.56
Coles	27-12N-7E	22459	Energy Prod. No. G-1 Arterburn	NAS-151	0.62
Coles	20-14N-7E	22450	Brehm No. 1 Lambert	NAS-155	0.54
Coles	16-13N-9E	2104	Union Oil of California No. 1 Moler	NAS-312	0.54
Crawford	2-5N-11W	524	Bell No. 1 Miller	NAS-156	0.49
Crawford	12-5N-14W	710	Doheny No. 1 Arnold	NAS-159, 161	0.68
Crawford	36-6N-11W	2498	Slape Drilling No. 1 Kincaid	NAS-162	0.55
Crawford	12-7N-11W	294	West Drilling No. 1 Brown	NAS-164	0.61
Crawford	31-7N-13W	30012	Illinois Oil Invest No. 1 Mallory et al.	NAS-166, 167	0.60
Crawford	20-5N-11W	8957	Getty Oil No. 21 Shoulders	DWS-151, 152, 153	0.58
Cumberland	4-10N-9E	21385	Texaco No. 1 McCandlish	NAS-169	0.56
DeWitt	1-20N-4E	391	Peoples Gas Light & Coke No. 1 Lamb	NAS-173	0.49
DeWitt	16-21N-3E	91	Harris No. 1 Lewin	NAS-316	0.50
Douglas	31-16N-8E	21220	Cabot Corp. No. 2 Cabot-Tuscola	NAS-319	0.57
Douglas	2-14N-10E	352	Beckner Drill. No. 1 Jividen	NAS-322	0.50
Edgar	4-14N-11W	517	Jones-Simpson Drill. No. 1 Steele-Moss	NAS-176	0.45
Edgar	1-14N-14W	966	Wauson Petroleum No. 1 Sims	NAS-177	0.50
Edgar	19-16N-13W	1209	Peoples Gas Light & Coke No. 1 Witt	05IL-1L1, 1L2, 1L4	0.46
Effingham	32-6N-5E	22498	Juniper Petroleum 12x-32 Gerth	NAS-031, 032	0.60
Effingham	31-9N-4E	22705	Tri Star Prod. No. 1-D Lancaster	02IL-1C1, 2C1, 3C1, 4C1, 4C2, 5C1, 5L2, 6C1, 6L2, 7C1, 8C1	0.51
Effingham	15-6N-6E	445	Kingwood Oil No. 1 McWhorter	DWS-555, 556, 557 NAS-483	0.60
Effingham	3-7N-7E	22476	Energy Resources of Indiana No. 1 Niemerg	NAS-180	0.56
Fayette	21-6N-2E	24969	Brehm No. 1 Ireland	NAS-326	0.56
Fayette	31-5N-3E	1741	Shell Oil No. 1 Ford	NAS-329	0.54
Fayette	12-4N-1W	25257	Helm Petroleum No. 1 Ballance	10IL-1L1, 1L2, 1L4	0.52
Fayette	24-6N-1W	825	Benedum Trees No. 1 Van Zant	07IL-1L2, 2L1, 3L1, 4L1, 4L2	0.51
Franklin	36-6S-2E	1572	Shell Oil No. 19 C.W.&F. Coal	NAS-334	0.63
Franklin	19-7S-2E	2641	Gallagher No. 1 Zeigler Coal & Coke	NAS-337	0.64
Franklin	2-5S-3E	22770	Brehm & Duke Res. No. 1 Clayton Hrs. Comm.	DWS-176, 177, 178	0.67
Fulton	10-6N-1E	22019	New Jersey Zinc No. H-16 Thompson	NAS-548, 549, 550, 551, 552	0.55
Fulton	13-8N-2E	22020	New Jersey Zinc No. H-23 Williams	NAS-553, 554, 555, 556	0.50
Gallatin	11-8S-10E	2832	Humble Oil No. 33 Busiek-Crawford	NAS-090, 091, 092	0.51

---

*Modified from Barrows and others (1979), Barrows and others (1980), Barrows and Cluff (1984), and unpublished data at the Illinois State, Indiana, and Kentucky Geological Surveys. Well ID (identification) numbers are the county numbers in Illinois, the permit numbers in Indiana, and the record numbers in Kentucky. Locations are Sec.-T.-R. in Illinois and Indiana and Carter coordinates in Kentucky. All of the vitrinite reflectance measurements upon which this compilation is based were performed by Mary H. Barrows and J. Wesley Dillon at the Illinois State Geological Survey during the late 1970s and the early 1980s. For those locations where more than one sample was analyzed, $\bar{R}_o$ values were averaged.

APPENDIX C — Continued

Mean random vitrinite reflectance ($\overline{R}_o$) data for the New Albany Shale in the Illinois Basin.

County	Location	Well ID	Well Name	Sample Number	$\overline{R}_o$
			Illinois (continued)		
Gallatin	29-9S-9E	3316	Texaco No. 1 Walters	NAS-093, 094, 095, 096, 528, 529, 530 DWS-1011, 1012, 1013	0.80
Greene	32-11N-11W	189	Kewanee Oil No. 1 Eula	NAS-102	0.47
Hamilton	1-4S-5E	1276	Kewanee Oil No. 1 Wellen	NAS-184, 186	0.75
Hamilton	13-6S-5E	760	Shell Oil No. 4 Nohava	NAS-190	0.69
Hamilton	6-6S-7E	3450	Texaco No. 1 Cuppy	NAS-192, 193, 493, 494 DWS-392, 393, 394, 395	0.74
Hardin	36-11S-7E	20746	Rector & Stone No. 1 Missouri (MO) Portland Cement	11IL-1C1, 7C1, 12C1, 18C1, 21C1	1.50
Hardin	11-12S-10E	49	Lucus No. 1 Herrin	NAS-565, 568	1.00
Henderson	32-8N-4W	20411	Northern Illinois Gas No. 1 RAR	04IL-9C1, 13C1, 14C1, 16C1, 17C1, 21C1, 25C1	0.48
Iroquois	21-24N-13W	996	Peoples Gas No. 1 Mumm	NAS-195, 196	0.52
Iroquois	13-25N-11W	1015	Peoples Gas No. 1 Keen	NAS-198	0.48
Jackson	11-7S-2W	1511	Texaco No. 1 Harsha	NAS-347	0.62
Jackson	21-10S-3W	1440	National Assoc. Pet. Co. No. 1 Hays	NAS-350	0.60
Jasper	1-8N-8E	22576	Total Leonard No. 1 Theoele	NAS-201	0.75
Jasper	17-5N-10E	1522	Pure Oil Co. No. A-5 Honey	NAS-446, 449	0.69
Jefferson	18-3S-1E	1167	Dunnill No. 1 Kujawa	NAS-033	0.60
Jefferson	32-4S-3E	22946	Juniper Petroleum No. 33x-32 Hayse	NAS-205	0.66
Jefferson	28-3S-2E	23131	Crystal Oil Co. No. 1 Story	NAS-354	0.72
Johnson	34-13S-3E	20285	Texas Pacific Oil No. 1 Farley	NAS-359, 360	0.89
Knox	2-11N-2E	605	Illinois Power No. G-2	NAS-362	0.62
Knox	31-11N-2E	21010	New Jersey Zinc No. J-16 Gumm	NAS-558, 559, 560, 561, 562	0.53
Lawrence	29-4N-12W	7425	Atlantic Richfield No. 77 Lewis	NAS-103, 104 DWS-203, 204, 205	0.58
Lawrence	9-3N-11W	27798	Schlensker Drill. No. 1 Seward	NAS-207, 208	0.54
Lawrence	25-3N-13W	2628	Highland Oil No. 1 Hobbs	NAS-213	0.63
Logan	7-19N-3W	113	Allspach No. 1 Park	NAS-107	0.44
Macon	36-16N-1E	21101	Corley No. 1 Hill	NAS-365	0.52
Macoupin	19-12N-6W	920	Wright No. 1 Thoron	NAS-368	0.46
Madison	35-5N-7W	1187	Hall No. 1 Wehling	NAS-036, 037	0.52
Marion	35-3N-2E	25806	Brehm No. 1 Behnke	NAS-211	0.58
Marion	25-4N-3E	5712	Total Leonard No. 1-25 Lane	NAS-371	0.54
Mason	3-19N-10W	62	Pinkston No. 1 Blessman	NAS-043	0.49
Mason	9-22N-7W	4	Engelke No. 1 Woodrow	NAS-453	0.51
Massac	23-14S-3E	32	Kahle No. 1 Harvick	NAS-569, 570, 571	0.92
McLean	26-23N-6E	357	Garland & Hoover No. 1 Green	NAS-227	0.51
Montgomery	33-12N-5W	347	Phillips Pet. Co. No. 5 Farmersville	NAS-378	0.48
Montgomery	11-9N-3W	21827	Mobil Oil Co. No. 1 DeWerff	NAS-376	0.58
Montgomery	11-8N-5W	702	The California Co. No. 1 Schmidt	NAS-458	0.52
Morgan	15-13N-8W	346	Panhandle E. Pipeline Co. No. 7-15 Whitlock	NAS-382	0.54
Peoria	11-7N-6E	700	Midland Electric Coal No. 1 Peters	08IL-7L1, 10L1, 16L1	0.48
Peoria	25-11N-8E	468	Prentiss No. 1 Coon	NAS-462	0.48
Perry	19-5S-2W	23255	Total Leonard Inc. No. 1 Pick	NAS-386	0.55
Perry	23-5S-3W	23234	Beeson No. 1 Joseph Porter Unit	DWS-479	0.53
Piatt	13-21N-6E	40	Union Hill Gas Storage No. 1 Buchan	NAS-229	0.54
Piatt	5-19N-5E	207	Texaco No. 1 Trenchard	NAS-388	0.49
Pike	32-3S-4W	7	Neal Co. No. 1 Crump	NAS-463	0.54
Pike	23-6S-3W	164	Texaco No. 1 Scott	NAS-468	0.58
Pope	2-11S-6E	20302	Texas Pacific No. 1 Streich Comm.	NAS-508, 509, 510	1.25
Pulaski	12-14S-1E	1	New Illinois Mid-Cont. No. 1A Herrin	NAS-572, 573	0.86
St. Clair	6-3S-6W	1757	Coral Oil No. 1 Schroeder	09IL-1L3	0.50
Saline	8-10S-5E	2400	Parker No. 1 Parker	NAS-392, 395	0.97
Saline	34-10S-6E	23981	Texas Pacific No. 1 Wells	NAS-118, 120, 121	1.01

APPENDIX C — Continued

Mean random vitrinite reflectance ($\bar{R}_o$) data for the New Albany Shale in the Illinois Basin.

County	Location	Well ID	Well Name	Sample Number	$\bar{R}_o$
Illinois (continued)					
Saline	32-10S-7E	3505	Texota Oil No. 1 King	NAS-123, 124, 125, 126	1.45
Saline	9-9S-5E	3631	Brehm Drill. & Prod. No. 1 Ozment	NAS-401	1.03
Sangamon	11-15N-3W	115	Miller No. 1 Sample	01IL-1L2, 4L1, 10L1, 11L1, 14L1, 16L1, 17L1, 19L1, 21L1	0.44
Sangamon	11-15N-3W	22304	Corley No. 1 Anderson	NAS-233	0.50
Sangamon	1-16N-6W	1441	Caney Oil No. 1 Eugene Schlitt	NAS-235	0.50
Schuyler	11-1N-3W	332	Kerwin No. 1 Wrench	NAS-469	0.55
Shelby	17-9N-3E	22024	Energy Resources No. 1 Gregg	NAS-406	0.52
Shelby	3-10N-5E	22034	Total Leonard Inc. No. 1 Engel	NAS-410	0.54
Shelby	19-14N-2E	1711	NEA YES Inc. No. 1 Stoggsdill	NAS-543	0.52
Tazewell	8-23N-2W	21198	Northern Illinois Gas No. 1 MAK	06IL-10C1, 13C1, 16C1, 18C1, 19C1, 20C1, 20C2, 25C1, 16C1BE, 19C1BE, 25C1BE	0.48
Tazewell	36-24N-7W	278	Central Light No. 1 Rutherford	NAS-414	0.51
Union	12-12S-1W	81	Fry No. 1 Hill	NAS-416	0.71
Vermilion	12-19N-11W	1848	Allied Chem. No. 1 Allied Chem.	NAS-237	0.56
Vermilion	10-23N-11W	1845	Peoples Gas No. 1 Layden	NAS-240	0.50
Vermilion	15-23N-14W	1825	Peoples Gas No. 1 Swanson	NAS-243	0.53
Wabash	9-1S-12W	26176	So. Triangle Oil No. D2 Zimmerman	NAS-128, 131	0.62
Washington	30-2S-3W	2866	Amoco Prod. No. 1 Kolweier	NAS-045	0.54
Washington	27-3S-1W	23041	Juniper Petroleum No. 24x-27 Kubiak	NAS-046	0.59
Washington	1-3S-4W	22957	Anschutz No. 1 Eigenrauch	NAS-050	0.53
Wayne	27-1N-7E	89	Pure Oil No. 3 Billington	NAS-053	0.70
Wayne	14-1N-8E	6524	Nation Oil No. 1 Van Fossan-Brown	NAS-058, 059	0.67
Wayne	28-1S-6E	503	Texaco No. 5 Fuhrer	NAS-061, 062	0.63
Wayne	29-2S-9E	4404	Collins Bros. No. 1 Hill	NAS-066, 067, 068	0.62
Wayne	4-3S-7E	4240	Savage/Zephyr No. 1 Sprague	NAS-071, 072	0.71
Wayne	21-1S-9E	842	Luttrell No. 1 Fetherling	NAS-420, 423	0.68
Wayne	34-1S-7E	29348	Hobson Oil No. 2 Taylor	12IL-1C1, 2C1, 3C1, 4C1	0.76
Wayne	17-3S-8E	29436	Jenkins No. 1 Simpson	13IL-6C2, 7C2, 9C2, 10C1, 15C1, 17C2, 19C1, 21C2, 23C4	0.73
Wayne	3-1S-7E	7731	Union Oil of California No. 1 Cisne Comm.	DWS-432, 433, 434	0.69
White	23-6S-9E	7815	Haley Prod. No. 1 Trainor	NAS-245, 247, 249	0.57
White	21-3S-9E	8269	National Oil Co. No. 1 Granger	NAS-429, 432	0.66
White	27-4S-14W	4694	Superior Oil No. C-17 Ford	03IL-3L1, CP16661-A, 18L1 19L2, 21L1, 25L1 DWS-020, 022	0.62
White	15-5S-9E	28436	Brehm No. 1 Reinwald	NAS-472, 475	0.67
Williamson	25-8S-3E	2531	Brehm No. 1 Harris Unit	NAS-252, 253	0.88
Woodford	28-27N-3W	235	Central Illinois Light No. C18 Cilco	NAS-135	0.58
Indiana					
Crawford	18-3S-1W	36106	Reynolds & Vincent No. 1 Goldman	NAS-274	0.54
Daviess	16-3N-7W	34032	North-American No. 1 O'Brian	NAS-265,265a	0.57
Dubois	19-2S-5W	40081	Anschutz Corp. No. 16-19 Voelkel	NAS-759	0.51
Floyd	16-3S-6E	114439	IGS SDH No. 309 Eve	NAS-760	0.51
Fountain	33-22N-7W	13097	Carter Oil No. 1 Vester	NAS-267	0.57
Fountain	22-20N-8W	19587	Crawford No. 1 Galloway	DWS-225, 226, 227	0.51
Greene	8-6N-5W	36022	Citizens Gas & Coke No. 9 Rollison	DWS-241, 242, 243	0.56
Harrison	3-6S-5E	109879	IGS SDH No. 308 Knear	NAS-761	0.44
Harrison	2-6S-4E	26612	Mason & Board No. 1 Garrett, Geyer, & Rodger	NAS-273, 273a	0.58
Hendricks	12-14N-1E	25818	Hyslope & Simpson No. 1 Bishop	NAS-289 DWS-264a, 265, 265a, 266	0.54
Knox	3N-10W	12116	Poe & Elliott No. 1 Guerrettaz	DWS-129, 130, 131	0.63

APPENDIX C — Continued

Mean random vitrinite reflectance ($\overline{R}_o$) data for the New Albany Shale in the Illinois Basin.

Indiana (continued)

County	Location	Well ID	Well Name	Sample Number	$\overline{R}_o$
Lawrence	20-5N-2E	29066	Texas Gas No. 2614 Brown	NAS-268 DWS-283, 283a, 284, 285	0.57
Marion	33-15N-3E		S. Harding St. Quarry	CP-1184	0.46
Martin	5-3N-4W	8133	Miles No. 1-A Crane	NAS-269	0.57
Monroe	8-9N-1E	26854	Indiana Gas & Water Co. No. 1 Fleener	DWS-310, 311, 312	0.54
Montgomery	14-17N-3W	15231	Zink No. 1 Kessler	NAS-283	0.50
Morgan	3-12N-1W	23811	Citizens No. 1 Neal	NAS-288	0.53
Owen	14-9N-5W	22853	Citizens No. 1 Kimble	NAS-287	0.52
Posey	18-5S-13W	33123	Rush Creek No. 1-D Noble, Stallings & Barrett	NAS-271	0.59
Posey	12-4S-14W	36605	Exxon No. 1 Ford-Corbin Farms	DWS-072, 073, 074	0.64
Posey	19-7S-13W	122811	General Electric No. 2 General Electric	DWS-101, 102, 103, 104	0.60
Putnam	12-12N-3W	17379	Dayton No. 1 Cook	NAS-275	0.53
Spencer	3-6S-4W	33711	Humley Resources No. 1 Racine	NAS-266	0.59
Sullivan	14-6N-10W	36216	Energy Resources of Indiana No. 1 Phegley Farms Inc.	01IN-1C1, 3C3, 4C1, 8C2	0.60
Sullivan	14-8N-8W	26164	Dining No. 1 Cox	NAS-270	0.64
Sullivan	36-7N-10W	29206	Miro No. 1 Hobbs	NAS-272	0.60
Sullivan	32-8N-8W	7236	Runyon No. 1 Ingram	NAS-286	0.56
Sullivan	36-8N-9W	27	Felmont Corp. No. 1 Riggs	DWS-336, 336a, 337, 337a, 338	0.67
Tippecanoe	8-23N-5W	23743	Continental Oil Co. No. 1 Warren	DWS-348, 349	0.55
Vermillion	9-16N-9W	2021190003	Food Mach. & Chem Co. No. WD-1 Newport Chem. Plant	DWS-361, 362, 363	0.54
Vermillion	27-14N-9W	34857	Triangle No. 1 Cheek	NAS-284	0.51
Warrick	36-4S-9W	8625	Reynolds No. 1 Weyerbacher	NAS-282	0.58
Washington	17-2N-5E	34379	Ace-Hi No. 1 Elliott	NAS-290	0.55

Kentucky

County	Location	Well ID	Well Name	Sample Number	$\overline{R}_o$
Allen	2-C-40	105998	Clements No. 1 Kelley	NAS-622, 623, 624	0.58
Allen	14-D-41	105997	Diversa Prod. No. 1 Vaughan	NAS-626, 627	0.58
Breckinridge	22-P-36	90316	Douthitt No. 1 Hendricks	NAS-660, 661, 662	0.59
Breckinridge	19-R-37	26546	Texas Gas Trans. No. 1 Kroush	NAS-599, 600	0.57
Breckinridge	10-N-39	90064	Lucus No. 1 Howard	NAS-640, 641, 642	0.59
Breckinridge	16-P-35	2484	Langford No. 1 Knight Brothers	DWS-1218, 1219, 1220	0.59
Breckinridge	12-N-37	26512	Sakellaris No. 1 Storms	NAS-732, 733, 734	0.60
Butler	9-I-33	89889	Miller No. 1 Orange	NAS-602, 603, 604	0.58
Butler	10-G-33	28420	Beaver Dam Coal No. 1 McKinley	NAS-666, 667, 668	0.55
Butler	10-K-35	28419	Miller et al. No. 1 Embry	NAS-663, 664, 665	0.58
Caldwell	5-G-20	2636	Rowe No. 1 Pettit	NAS-672, 674	0.74
Caldwell	11-I-19	2675	Dunbar No. 1 Brown	NAS-669, 670, 671	0.68
Christian	21-C-23	105996	Sargent No. 1 Bodie	NAS-631, 632, 633	0.59
Christian	7-G-25	28029	Ames O & G No. 1 Croft	NAS-628, 629, 630	0.56
Christian	9-E-25	106140	Burlew No. 1 Hudson	NAS-738, 739, 740	0.65
Christian	12-G-25	28025	Orbit Gas No. 1 Clark	01KY-1L1, 2L1, 3L1 4L1, 5L1, 7L1, 8L1, 10L1, 11L1, 12L1, 13L1, 1C1, 2C1, 3C1, 4C1, 5C1 7C1, 8C1, 9C1, 10C1, 11C1, 12C1, 13C1	0.50
Crittenden	25-I-17	84714	Pate No. 1 Linzy	NAS-598	0.89
Daviess	3-N-30	7696	Warren Energy Corp. No. 2 Boarman Bros. & Ellis Est.	NAS-657, 658, 659	0.57
Daviess	8-N-30	7701	Warren Energy Corp. No. 1 Boarman Bros. et al.	NAS-654, 655, 656, 714, 715, 716	0.59
Daviess	8-N-30	7698	Warren Energy Corp. No. 3 Boarman Bros. et al.	NAS-717, 718, 719	0.57
Daviess	10-N-28	7614	Warren Energy Corp. No. 1 Fulkerson-Brooke	NAS-720, 721, 722	0.58
Edmonson	15-H-39	101553	McGinley No. 1 Elmore	NAS-676, 677, 678	0.65

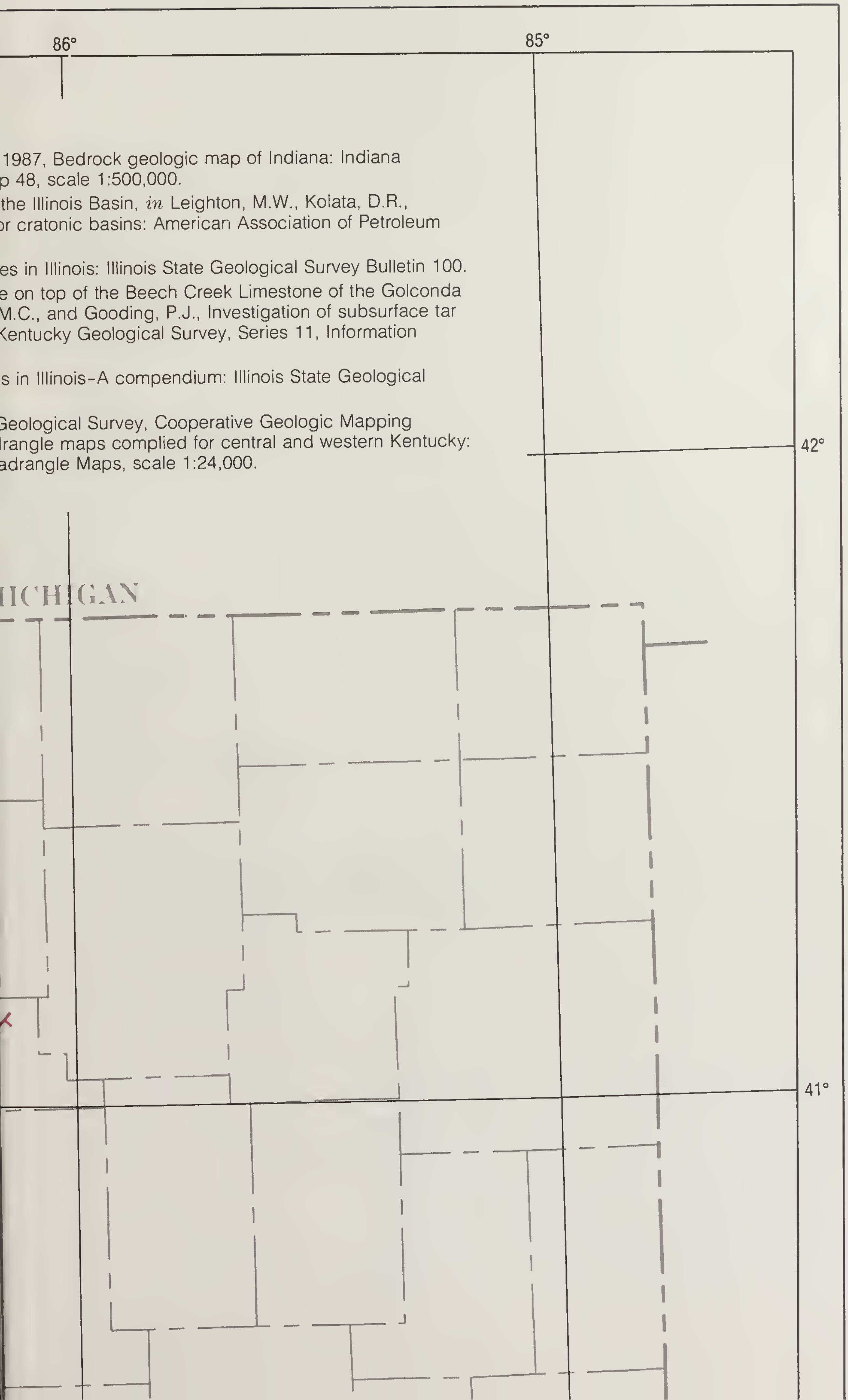
APPENDIX C — Continued

Mean random vitrinite reflectance ($\bar{R}_o$) data for the New Albany Shale in the Illinois Basin.

County	Location	Well ID	Well Name	Sample Number	$\bar{R}_o$
			Kentucky (continued)		
Edmonson	8-I-39	105995	Kingwood Oil & KY Natl. Gas No. 1 Kyrock Asphalt	NAS-675	0.65
Edmonson	11-H-41	8252	Smith No. 1 Marco Development	NAS-741, 742, 743	0.60
Grayson	8-K-38	28447	Equitable Life No. 1 Seaton	NAS-593, 594, 595, 596, 597	0.53
Grayson	14-K-38	8943	Equitable Life No. 1 Hobart Lash	NAS-705, 706, 707	0.57
Grayson	22-K-38	28445	Equitable Life No. 2 Johnson	NAS-708, 709, 710	0.57
Grayson	16-M-36	9037	Quasar Inc. No. 1 Porter	NAS-723, 724, 725	0.60
Grayson	10-L-36	8974	Texas Gas No. 1 Shain	NAS-744	0.58
Hancock	5-Q-33	59288	Miller No. 1 Mason	NAS-583, 584, 585	0.60
Hancock	19-Q-33	27911	Evcus Corp. No. 1 Dejarnett	NAS-605, 606, 607	0.69
Hardin	20-M-42	105994	Bland No. 4 Williams	NAS-679, 680, 681	0.55
Hardin	21-O-42	105993	KenTex No. 1 Tabb	NAS-682, 683, 684	0.55
Hardin	19-P-42	105992	Schook No. 1 Pyle	NAS-685, 686	0.53
Henderson	10-O-23	25124	Phillips Pet. No. 1 Shaffer Hrs.	NAS-690, 691, 692	0.60
Henderson	22-Q-25	25120	Magnolia Pet. No. 1 Casey	NAS-687, 688, 689	0.57
Hopkins	14-L-25	28612	Ryan No. 1 Shelton	NAS-608, 609, 610	0.68
Livingston	18-H-14	85194	Dunn No. 1 Dunn	NAS-750, 751, 752	0.93
Logan	19-E-30	12561	Wiser Oil No. 1 Stokes	NAS-756, 757	0.59
Logan	3-F-30	12613	Sullivan No. 1 Poque	NAS-611	0.51
Lyon	12-G-16	12829	Marhill & Kaufman No. 1 Timmons	NAS-634, 636	0.56
McCracken	17-G-12	28604	White No. 1 Jackson	NAS-612, 613	0.71
McLean	21-L-28	72371	S. Penn Oil No. 1 Brown	NAS-592	0.60
McLean	24-M-28	13557	Tamarack Pet. No. 3 Conrad	NAS-589, 590, 591	0.62
McLean	13-M-29	26529	Van Tuhl Drill. Co. No. 1 Murphy	NAS-586, 587, 588	0.61
Meade	22-R-40	105991	Vickers and Thrasher No. 1 Miller	NAS-637, 638, 639	0.60
Muhlenberg	16-H-29	28613	Wilson No. 1 White-Gilman-Cisney	NAS-693, 694, 695	0.61
Ohio	11-M-32	105990	Lewis et al. No. 1 Miller	NAS-615	0.57
Ohio	16-M-34	15672	Richard Beeson No. 1 Johnston	NAS-711, 712, 713	0.59
Ohio	13-N-32	15716	Warren Energy Corp. No. 1 McKinley	NAS-726, 727, 728	0.58
Ohio	13-N-32	15721	Warren Energy Corp. No. 1 Reisz et al.	NAS-729, 730, 731	0.58
Simpson	21-C-36	105989	Friendship No. 1 Hunt	NAS-643	0.56
Todd	1-C-28	29191	Porter No. 1 Wade	NAS-650	0.63
Todd	20-C-28	17055	Jarvis No. 1 Chastain	NAS-647, 649	0.63
Todd	16-G-28	58993	Putnam et al. No. 1 Glenn	NAS-644, 645, 646	0.61
Trigg	1-C-22	85153	Adams No. 1 Dawson	NAS-698	0.55
Trigg	25-E-20	28616	W. KY Gas Co. No. 1 Trammel	NAS-617, 618, 619	0.62
Union	15-N-21	17212	Ashland No. F-1-F Camp Breckinridge	NAS-651, 652, 653	0.90
Union	4-O-21	25119	Carter Oil No. 13 Culver Hrs.	NAS-699, 700, 701	0.61
Warren	1-E-38	105988	Hart No. 1 Corbitt	NAS-620, 621	0.54
Warren	25-G-36	89627	Stinson No. 1 Robinson	NAS-702, 703, 704	0.59

GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 1



1987, Bedrock geologic map of Indiana: Indiana
p 48, scale 1:500,000.

the Illinois Basin, *in* Leighton, M.W., Kolata, D.R.,
or cratonic basins: American Association of Petroleum

es in Illinois: Illinois State Geological Survey Bulletin 100.

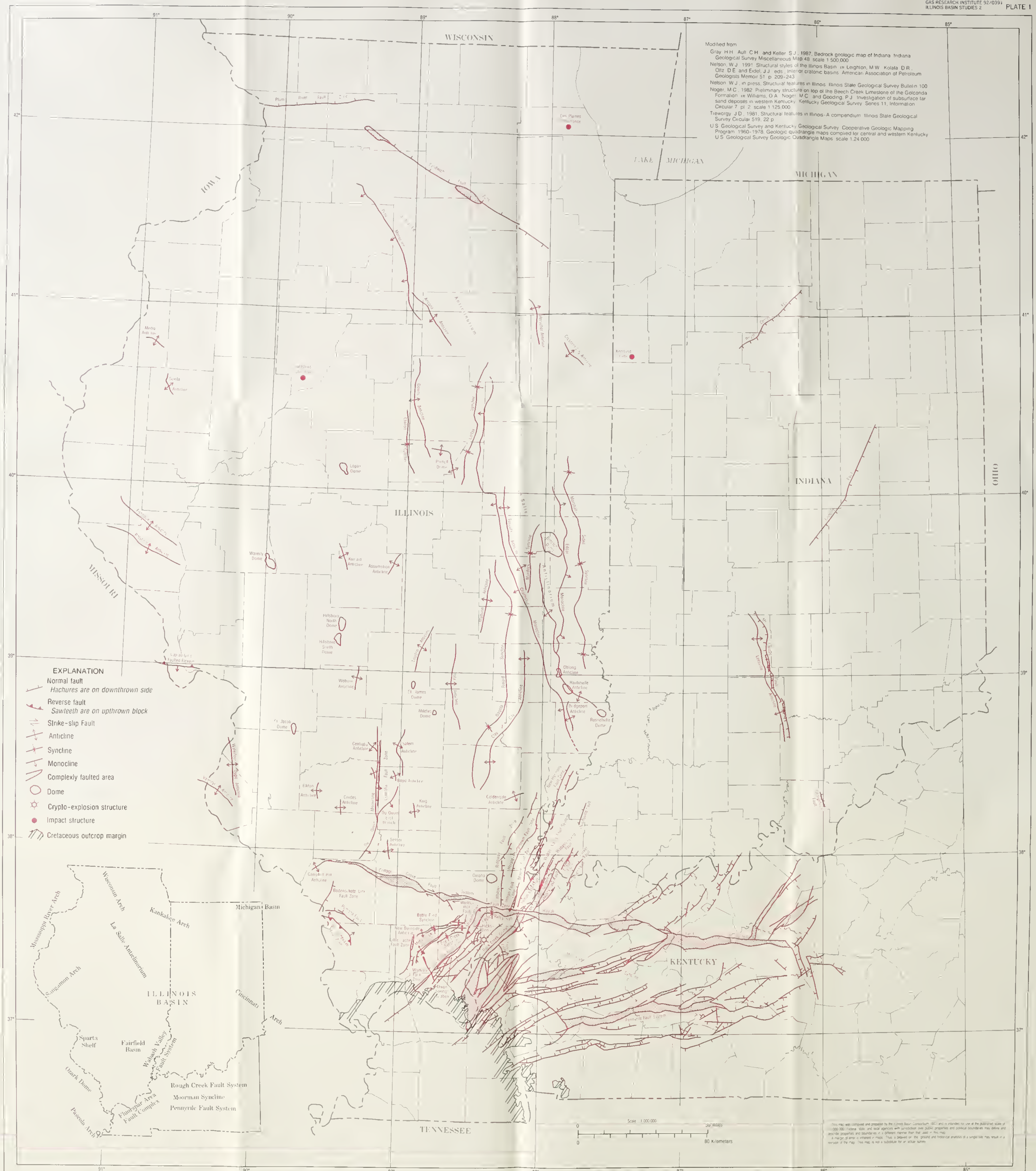
e on top of the Beech Creek Limestone of the Golconda
M.C., and Gooding, P.J., Investigation of subsurface tar
Kentucky Geological Survey, Series 11, Information

s in Illinois-A compendium: Illinois State Geological

Geological Survey, Cooperative Geologic Mapping
drangle maps complied for central and western Kentucky:
adrangle Maps, scale 1:24,000.

GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 1



Modified from

Gray H H, Ault C H and Keller S J, 1987, Bedrock geologic map of Indiana Indiana Geological Survey Miscellaneous Map 48 scale 1 500,000

Nelson, W J 1991 Structural styles of the Illinois Basin *in* Leighton, M W Kolata D R, Oltz D E and Eidel, J J eds, Interior cratonic basins American Association of Petroleum Geologists Memoir 51 p 209-243

Nelson W J, in press, Structural features in Illinois Illinois State Geological Survey Bulletin 100

Noger, M C, 1982 Preliminary structure on top of the Beech Creek Limestone of the Golconda Formation *in* Williams, O A Noger M C and Gooding, P J Investigation of subsurface tar sand deposits in western Kentucky Kentucky Geological Survey Series 11, Information Circular 7 pl 2 scale 1 125,000

Treworgy J D, 1981, Structural features in Illinois-A compendium Illinois State Geological Survey Circular 519, 22 p

U S Geological Survey and Kentucky Geological Survey Cooperative Geologic Mapping Program 1960-1978, Geologic quadrangle maps compiled for central and western Kentucky U S Geological Survey Geologic Quadrangle Maps scale 1 24 000

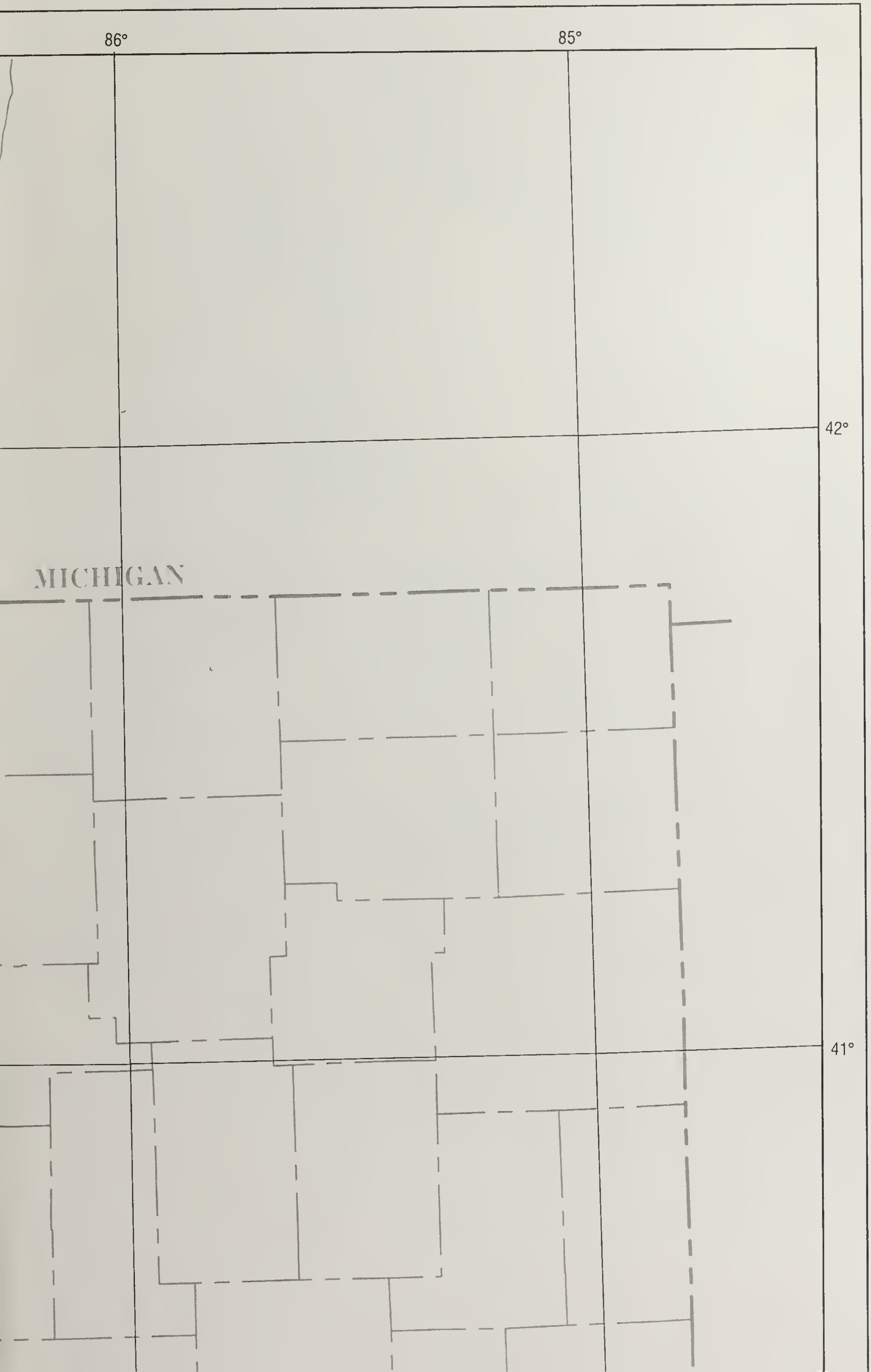
Base modified from U S Geological Survey maps of Indiana and Kentucky, scale 1 500,000, Illinois base from ILLIMAP digital files of U S Geological Survey 7 5' and 15' quadrangles
Universal Transverse Mercator Projection Reference Spheroid - Clarke, 1866, UTM zone 16

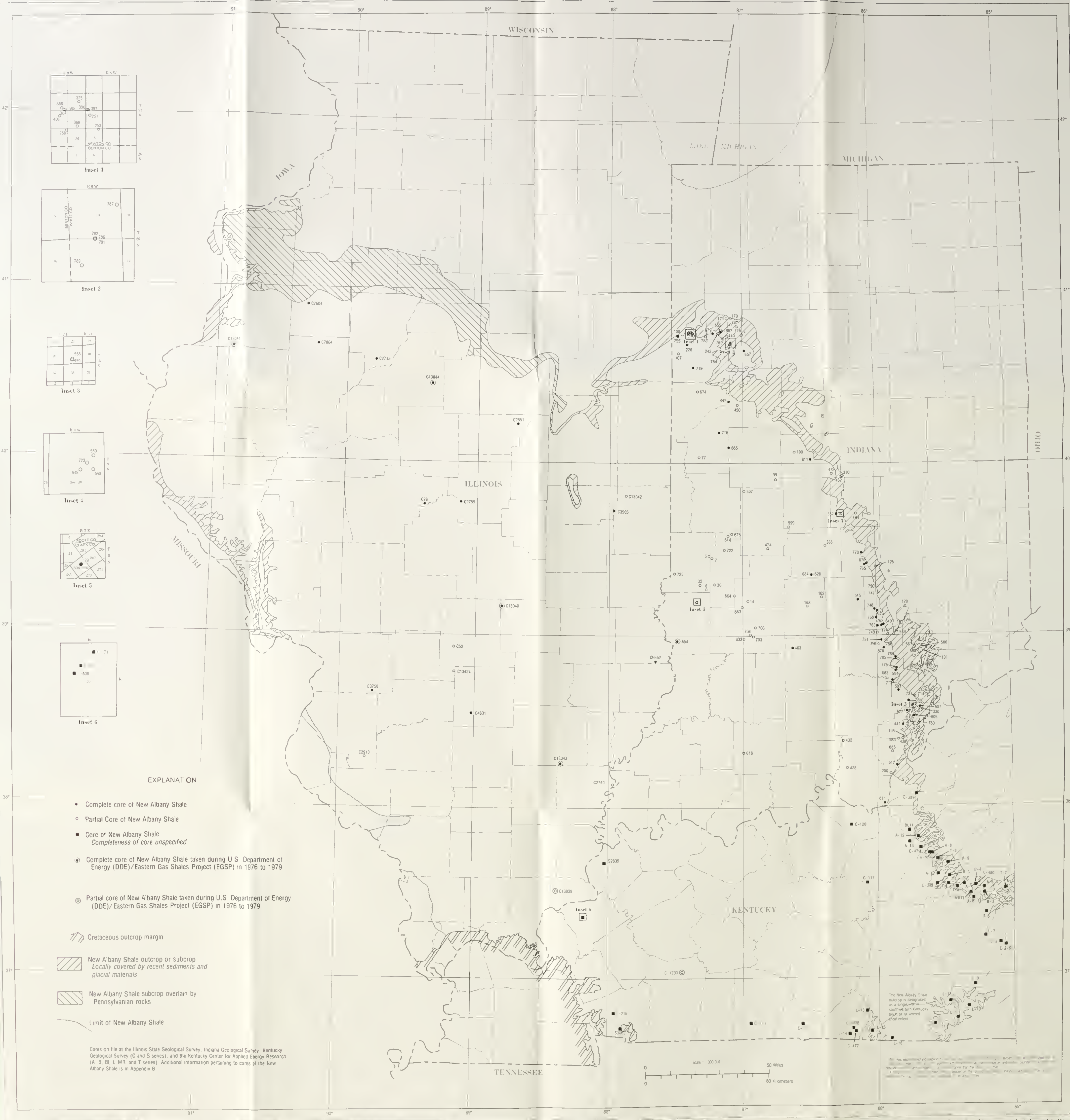
MAP SHOWING MAJOR STRUCTURAL FEATURES OF THE ILLINOIS BASIN

Compiled by
Wayne T. Frankie and Donald K. Lumm, Illinois State Geological Survey
Wesley S. Boberg, Indiana Geological Survey
Terence Hamilton-Smith and M.C. Noger, Kentucky Geological Survey
1994

Production of this map was funded in part by the Gas Research Institute Contract No 5090-213-1975 and the Illinois Basin Consortium The Illinois Basin Consortium consists of the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey Data compiled through July 1991 Drafted by Kimberly H Sowder, Indiana Geological Survey Photography/reprographics by Barbara T Hill, Indiana Geological Survey

PLATE 2





EXPLANATION

- ● Complete core of New Albany Shale
- ○ Partial Core of New Albany Shale
- ■ Core of New Albany Shale
  Completeness of core unspecified
- ⊙ Complete core of New Albany Shale taken during U S Department of Energy (DDE)/Eastern Gas Shales Project (EGSP) in 1976 to 1979
- ◎ Partial core of New Albany Shale taken during U.S Department of Energy (DDE)/Eastern Gas Shales Project (EGSP) in 1976 to 1979
- ▨ Cretaceous outcrop margin
- ▨ New Albany Shale outcrop or subcrop
  Locally covered by recent sediments and glacial materials
- ▨ New Albany Shale subcrop overlain by Pennsylvanian rocks
- — Limit of New Albany Shale

Cores on file at the Illinois State Geological Survey, Indiana Geological Survey Kentucky Geological Survey (C and S series), and the Kentucky Center for Applied Energy Research (A B, BI, L, MR and T series) Additional information pertaining to cores of the New Albany Shale is in Appendix B

Base modified from U S Geological Survey maps of Indiana and Kentucky, scale 1 500,000, Illinois base from ILLIMAP digital files of U S Geological Survey 7 5′ and 15′ quadrangles
Universal Transverse Mercator Projection Reference Spheroid - Clarke, 1866, UTM zone 16

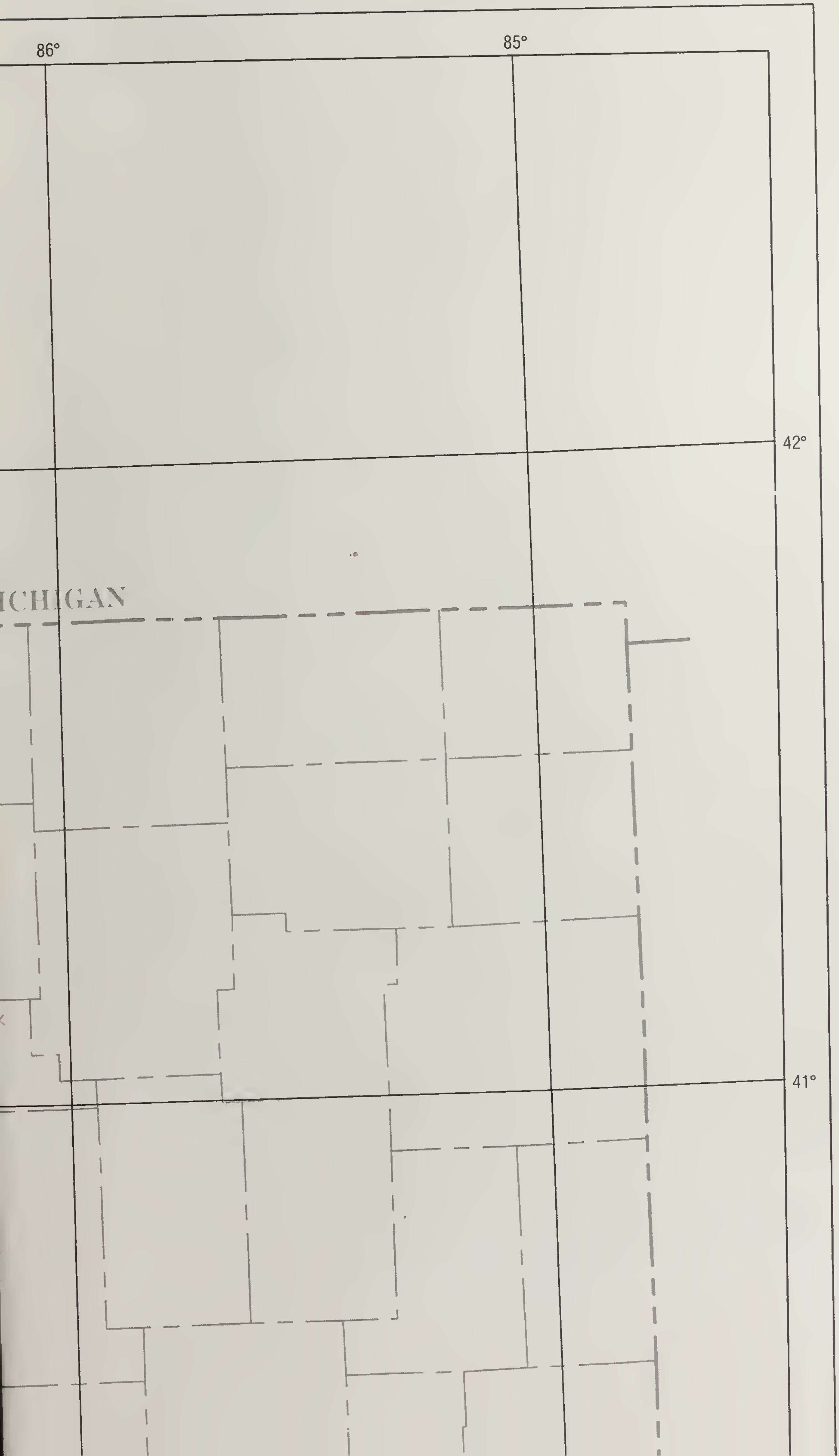
MAP SHOWING LOCATIONS OF CORES OF THE NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

Compiled by
Zinta Smidchens and Wesley S. Boberg, Indiana Geological Survey
Wayne T. Frankie and Donald K. Lumm, Illinois State Geological Survey
Terence Hamilton-Smith, Kentucky Geological Survey
1994

Production of this map was funded in part by the Gas Research Institute Contract No 5090-213-197
and the Illinois Basin Consortium The Illinois Basin Consortium consists of the Illinois State Geological Survey the Indiana Geological Survey, and the Kentucky Geological Survey Data compiled through July 1991 Drafted by Kimberly H Sowder, Indiana Geological Survey Photography/reprographics by Barbara T Hill, Indiana Geological Survey

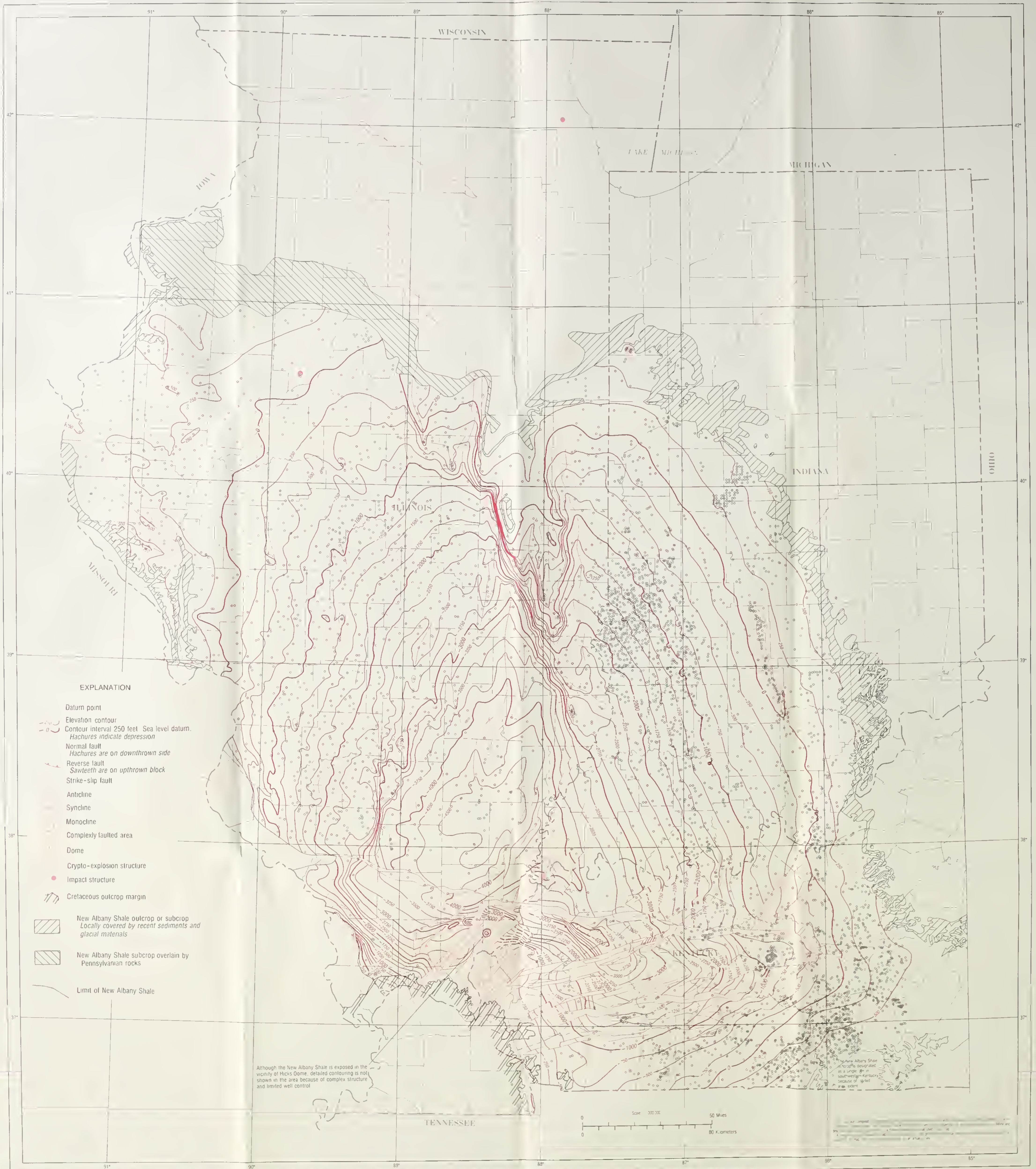
GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 3



GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 3


WISCONSIN
IOWA
LAKE MICHIGAN
MICHIGAN
ILLINOIS
INDIANA
OHIO
MISSOURI
KENTUCKY
TENNESSEE
91°
90°
89°
88°
87°
86°
85°
42°
41°
40°
39°
38°
37°
EXPLANATION
Datum point
Elevation contour
Contour interval 250 feet Sea level datum.
Hachures indicate depression
Normal fault
Hachures are on downthrown side
Reverse fault
Sawteeth are on upthrown block
Strike-slip fault
Anticline
Syncline
Monocline
Complexly faulted area
Dome
Crypto-explosion structure
Impact structure
Cretaceous outcrop margin
New Albany Shale outcrop or subcrop
Locally covered by recent sediments and glacial materials
New Albany Shale subcrop overlain by Pennsylvanian rocks
Limit of New Albany Shale
0
50 Miles
0
80 Kilometers

Although the New Albany Shale is exposed in the vicinity of Hicks Dome, detailed contouring is not shown in the area because of complex structure and limited well control

Base modified from U.S. Geological Survey maps of Indiana and Kentucky scale 1 500,000, Illinois base from ILLIMAP digital files of U.S. Geological Survey 7.5′ and 15′ quadrangles
Universal Transverse Mercator Projection Reference
Spheroid - Clarke, 1866, UTM zone 16

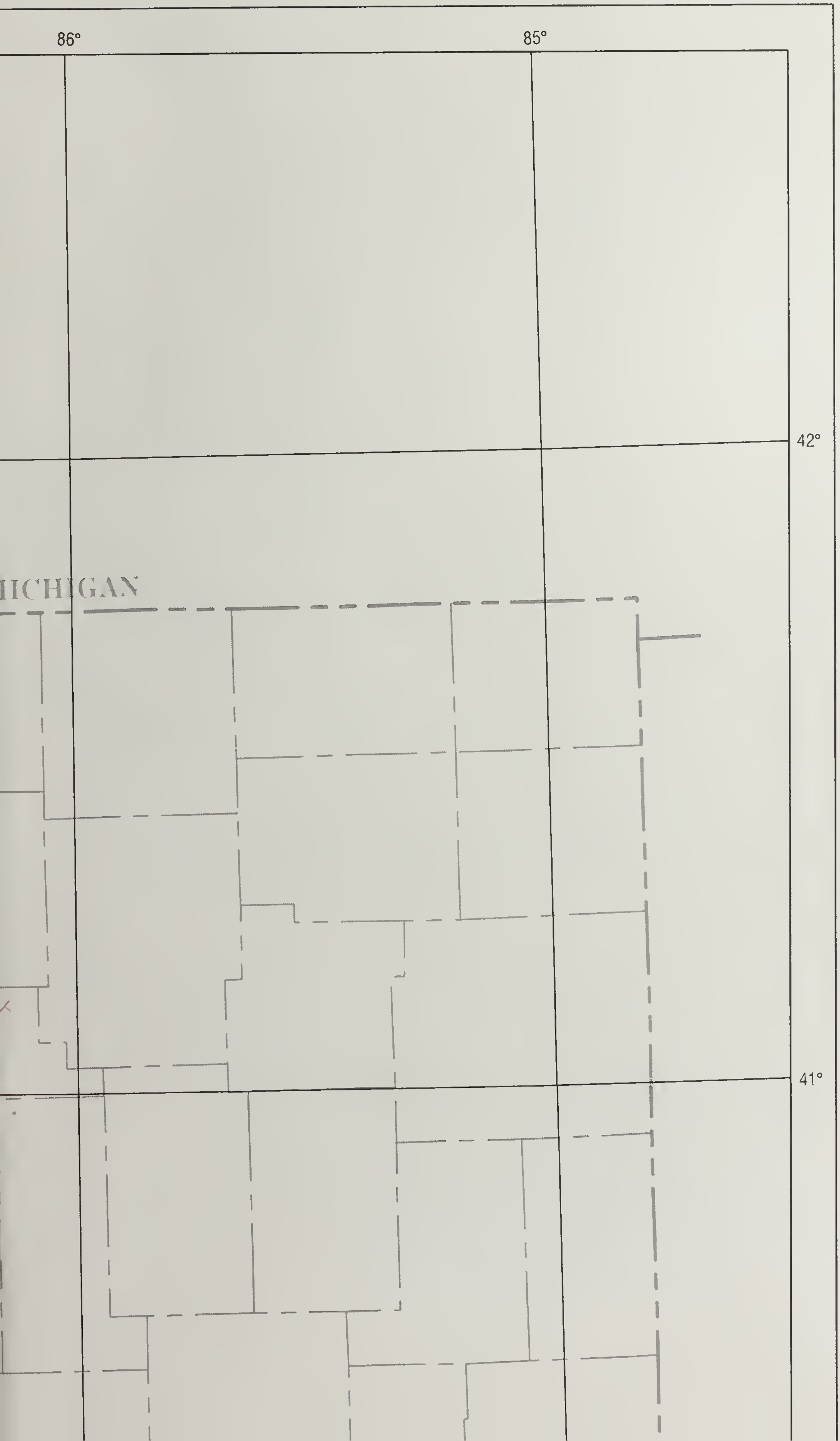
MAP SHOWING ELEVATION OF THE TOP OF THE NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

Compiled by
Wayne T. Frankie and Donald K. Lumm, Illinois State Geological Survey
Wesley S. Boberg, Nancy R. Hasenmueller, and Zinta Smidchens, Indiana Geological Survey
Terence Hamilton-Smith, Kentucky Geological Survey
1994

Production of this map was funded in part by the Gas Research Institute Contract No 5090-213-1975 and the Illinois Basin Consortium The Illinois Basin Consortium consists of the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey Data compiled through July 1991 Drafted by Kimberly H Sowder, Indiana Geological Survey Photography/reprographics by Barbara T Hill, Indiana Geological Survey

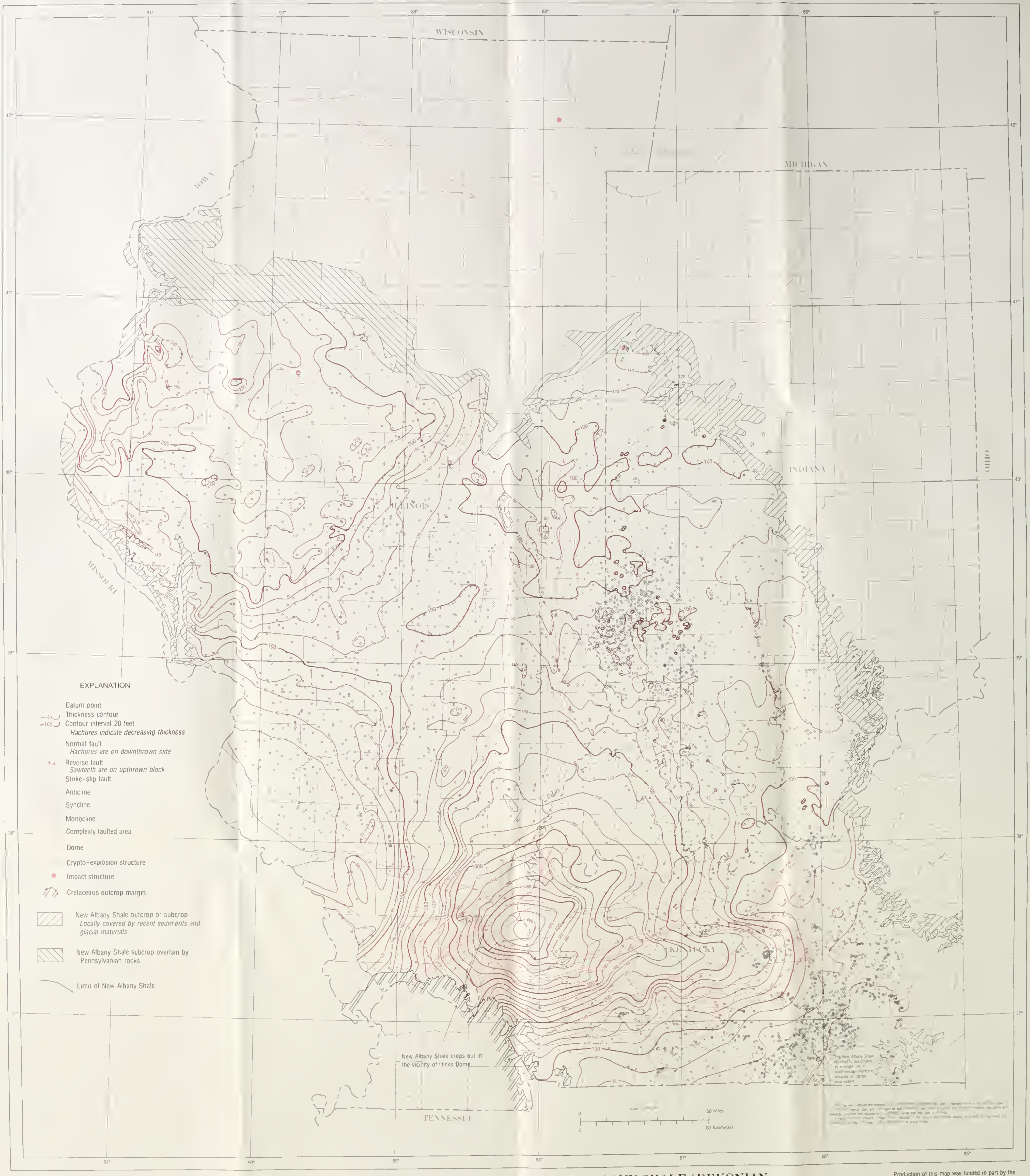
GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 4



GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 4


91°
90°
89°
88°
87°
86°
85°
42°
41°
40°
39°
38°
37°
WISCONSIN
IOWA
MICHIGAN
ILLINOIS
INDIANA
OHIO
MISSOURI
KENTUCKY
TENNESSEE
EXPLANATION
Datum point
80
100
Thickness contour
Contour interval 20 feet
Hachures indicate decreasing thickness
Normal fault
Hachures are on downthrown side
Reverse fault
Sawteeth are on upthrown block
Strike-slip fault
Anticline
Syncline
Monocline
Complexly faulted area
Dome
Crypto-explosion structure
Impact structure
Cretaceous outcrop margin
New Albany Shale outcrop or subcrop
Locally covered by recent sediments and glacial materials
New Albany Shale subcrop overlain by Pennsylvanian rocks
Limit of New Albany Shale
New Albany Shale crops out in the vicinity of Hicks Dome.
0
50 Miles
0
80 Kilometers

Base modified from U S Geological Survey maps of Indiana and Kentucky scale 1 500,000, Illinois base from ILLIMAP digital files of U S Geological Survey 7 5′ and 15′ quadrangles
Universal Transverse Mercator Projection Reference Spheroid - Clarke, 1866, UTM zone 16

MAP SHOWING TOTAL THICKNESS OF THE NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

Compiled by
Wayne T. Frankie and Donald K. Lumm, Illinois State Geological Survey
Wesley S. Boberg, Nancy R. Hasenmueller, and Zinta Smidchens, Indiana Geological Survey
Terence Hamilton-Smith, Kentucky Geological Survey
1994

Production of this map was funded in part by the Gas Research Institute Contract No 5090-213-1975 and the Illinois Basin Consortium The Illinois Basin Consortium consists of the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey Data compiled through July 1991 Drafted by Kimberly H Sowder, Indiana Geological Survey Photography/reprographics by Barbara T Hill, Indiana Geological Survey

I 557.7
IL I
No. 2
c. 3

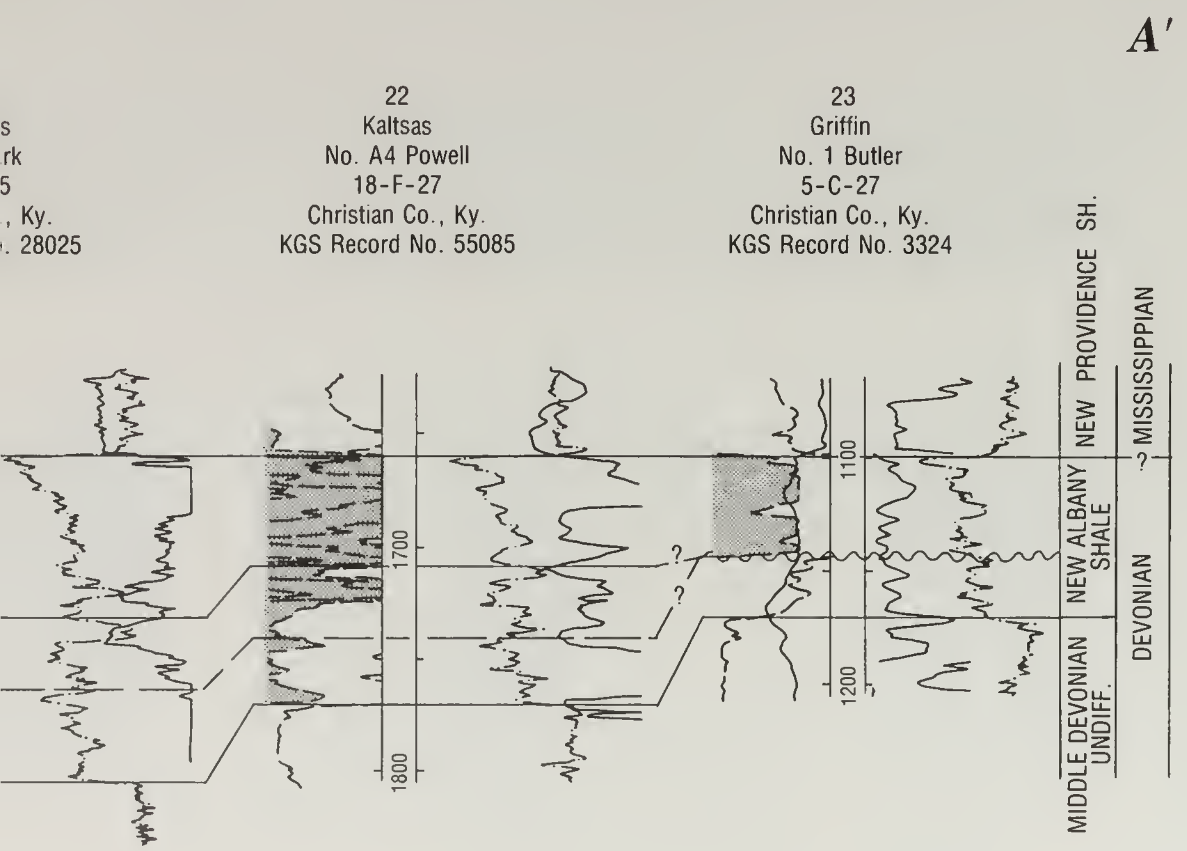
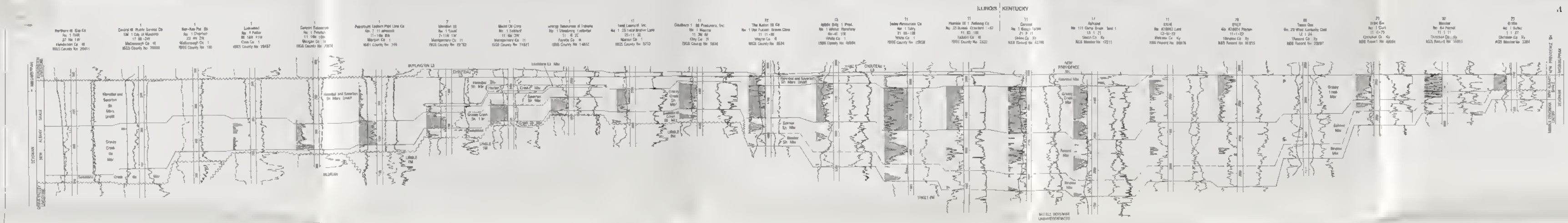
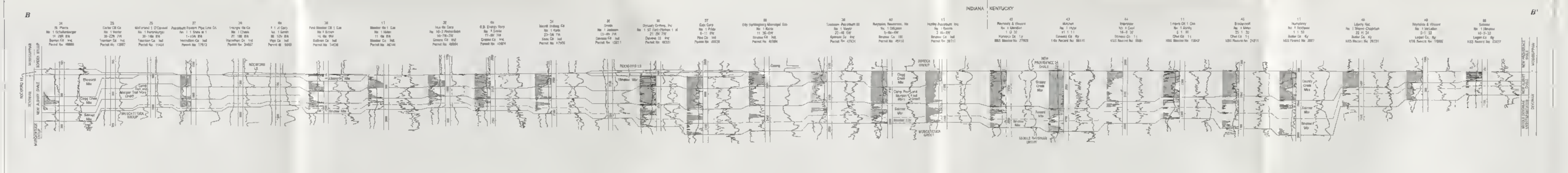
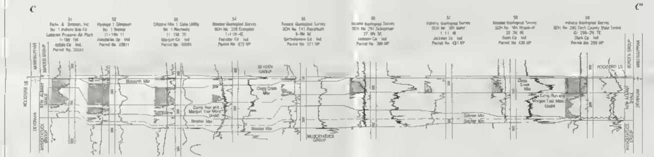


PLATE 5







Production of this plate was funded in part by the Gas Research Institute (Contract No. 5085-211-1078) and the Illinois Basin Consortium. The Illinois Basin Consortium consists of the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey

EXPLANATION

Correlation lines

Questionable correlation or contact

Unconformity

Facies intertonguing

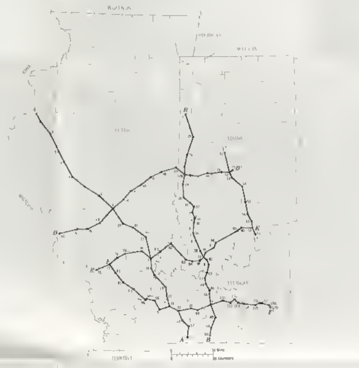
Vertical cutoff, nomenclatural boundary

Depths shown on cross sections are measurements from the surface

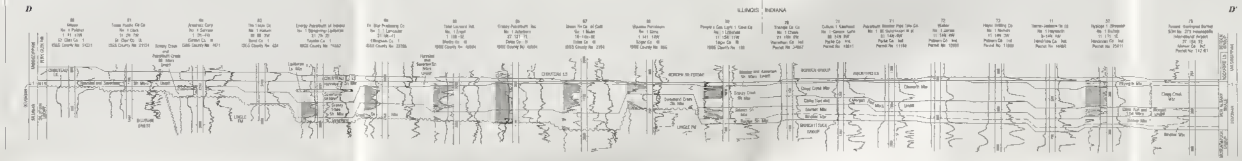
Vertical scale 1 inch =100 feet

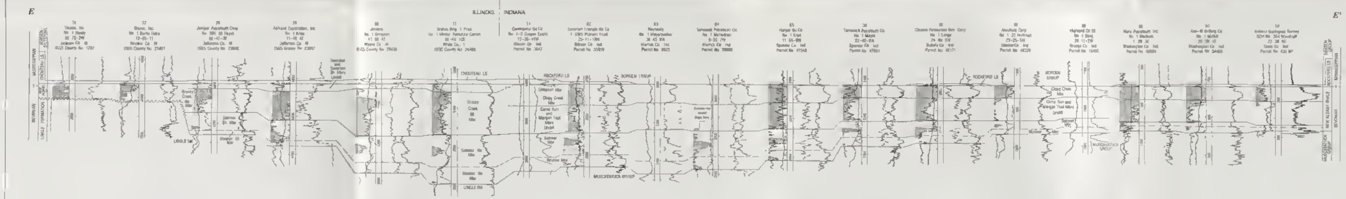
No horizontal scale for cross sections

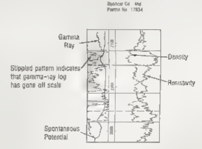
Datum plane is top of New Albany Shale. In some areas the New Albany Shale is unconformable with the overlying stratigraphic unit



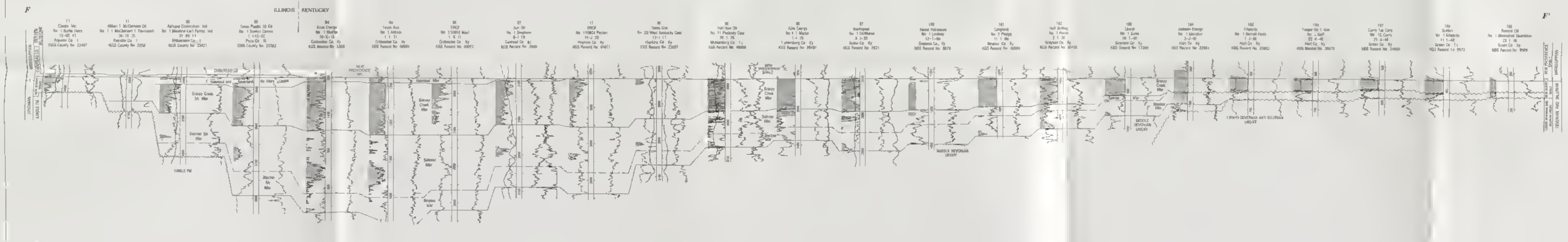
INDEX MAP






Gamma Ray
Stippled pattern indicates that gamma-ray log has gone off scale
Spontaneous Potential
Density
Resistivity

GEOPHYSICAL LOG KEY



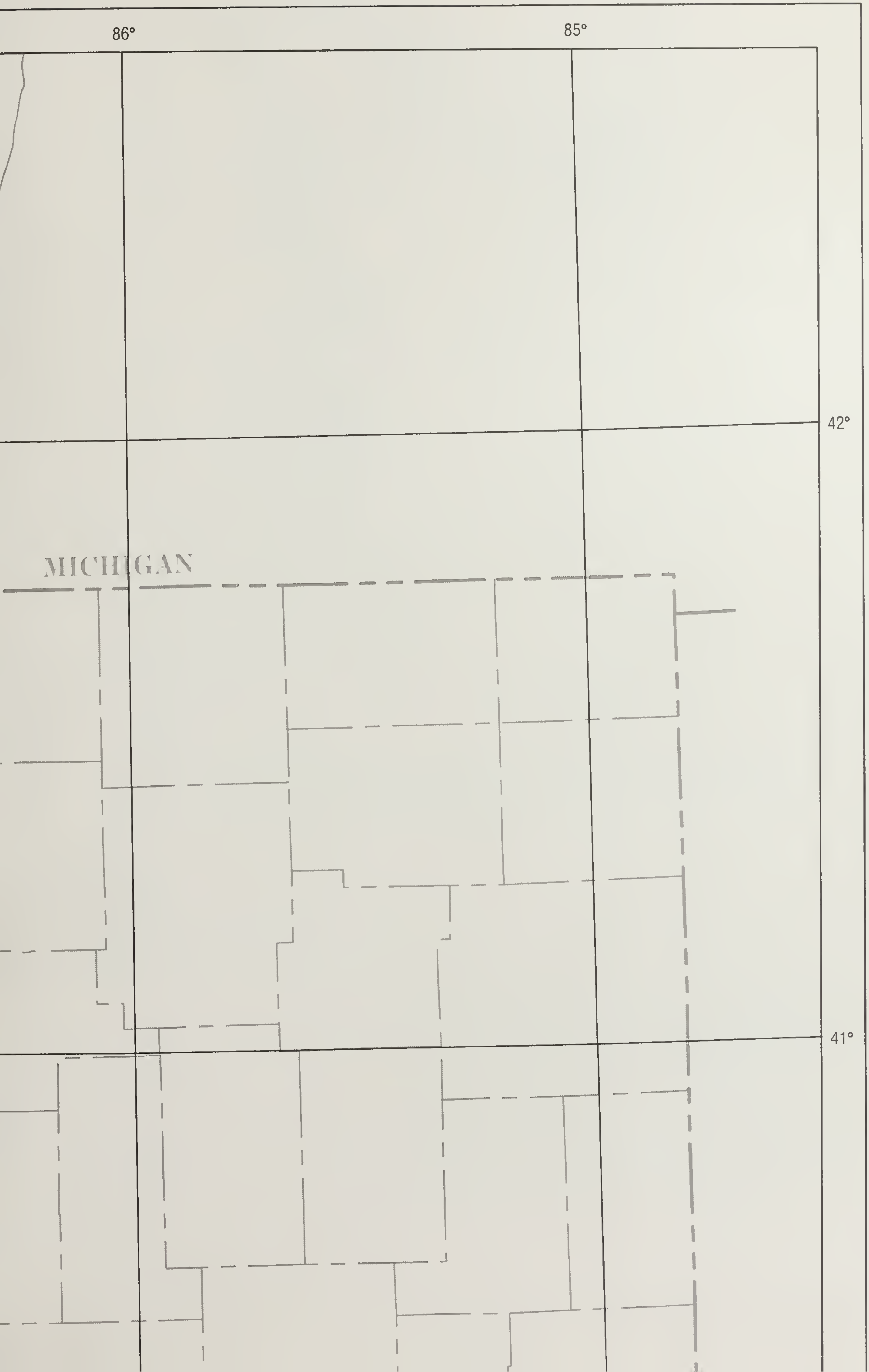
STRATIGRAPHIC CROSS SECTIONS SHOWING MEMBERS OF THE NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

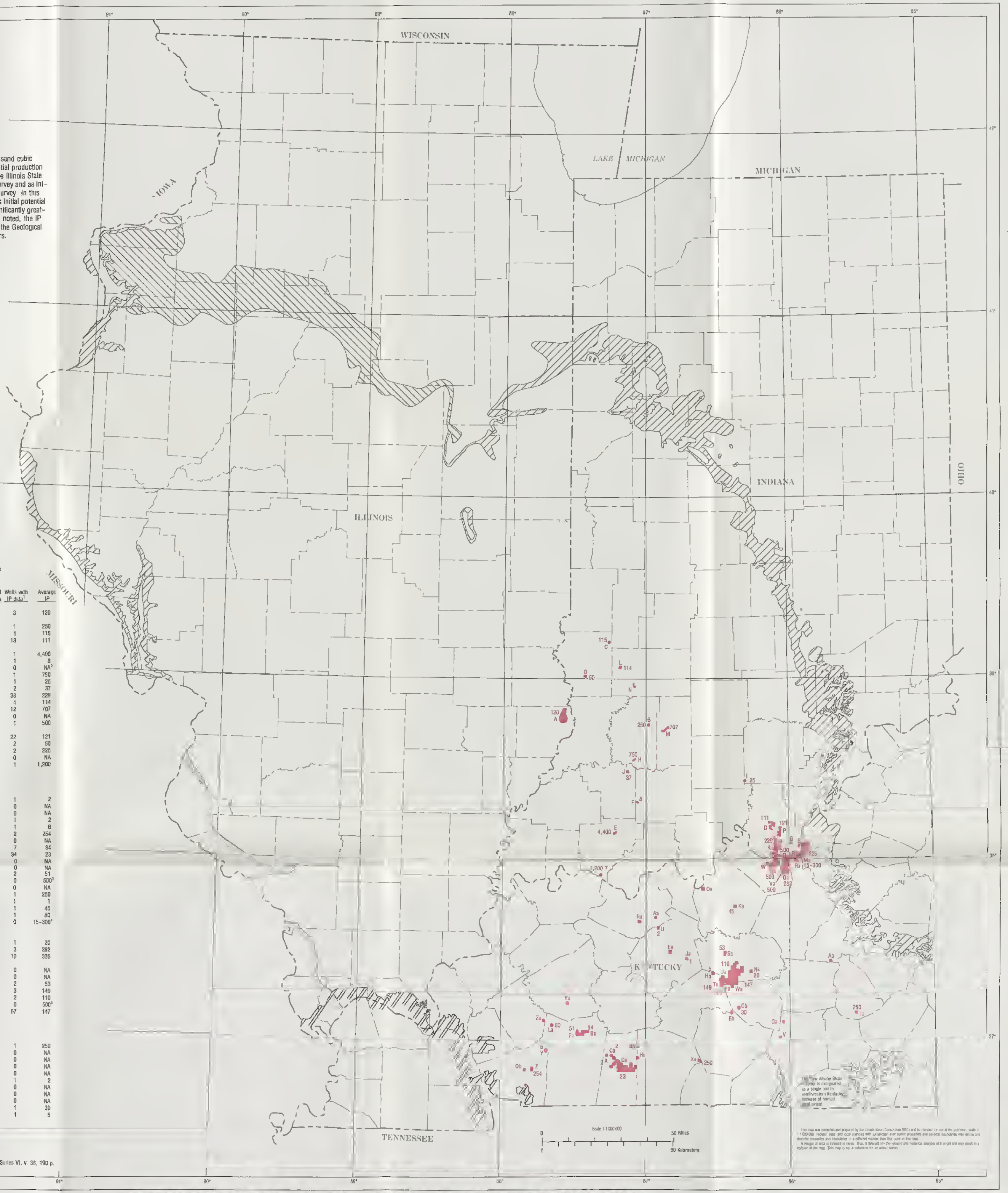
Compiled by
Wesley S. Boberg, Indiana Geological Survey
Donald K. Lumm and Wayne T. Frankie, Illinois State Geological Survey
Terence Hamilton-Smith, Kentucky Geological Survey
1994

Drafted by [illegible] and [illegible]
Illinois Geological Survey

GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 6





EXPLANATION

▨	Area of gas field
●	Single gas well
50	Average initial potential (IP) measured in thousand cubic feet per 24 hours (MCFGPD). Results of initial production tests are reported as initial production to the Illinois State Geological Survey and Indiana Geological Survey and as initial open flow to the Kentucky Geological Survey. In this report initial production tests are reported as initial potential (IP). These measurements are generally significantly greater than actual production. Unless otherwise noted, the IP values are from unpublished data on file at the Geological Surveys as reported by oil and gas operators.
A	Index letter corresponds to table (below)
	Cretaceous outcrop margin
▨	New Albany Shale outcrop or subcrop *Locally covered by recent sediments and glacial materials*
▧	New Albany Shale subcrop overlain by Pennsylvanian rocks
	Limit of New Albany Shale

Locations and average IP for New Albany Shale gas fields in the Illinois Basin

State	Index Letter	Field Name	County	Location T,R	Total wells	Wells with IP data[1]	Average IP
Illinois	A	Russellville	Lawrence	4N, 11W	4	3	120
Indiana	B	Bramble	Daviess	4N, 5W	1	1	250
	C	Coalmont West	Sullivan	9N, 8W	1	1	115
	D	Corydon	Harrison	3S, 3-4E	14	13	111
				4S, 4E			
	E	Dickeyville	Warrick	4S, 7W	3	1	4,400
	F	Duff	Dubois	2S, 6W	1	1	8
	G	Elizabeth	Harrison	5S, 5E	1	0	NA[2]
	H	Glendale	Daviess	2N, 6W	1	1	750
	I	Hardinsburg	Washington	1S, 2E	1	1	25
	J	Ive East	Pike	1N 6-7W	2	2	37
	K	Laconia	Harrison	4-6S, 4E	92	38	229
	L	Linton	Greene	7N 7W	4	4	114
	M	Loogootee North	Martin	3-4N, 4W	12	12	707
	N	Lyons	Greene	6N, 6W	1	0	NA
	O	New Boston	Harrison	5S, 5E	6	1	500
				6S, 4-5E			
	P	New Middletown	Harrison	4S, 4E	27	22	121
	Q	Paxton West	Sullivan	7N, 9W	3	2	50
	R	Rosewood	Harrison	5-6S 5E	20	2	225
	S	Rosewood North	Harrison	5S, 5E	4	0	NA
	T	Yankeetown	Warrick	7S, 8W	1	1	1,200
				Carter Quad			
Kentucky	U	Bells Run	Ohio	N-32	1	1	2
	V	Bon Ayr	Barren	G-42	NA	0	NA
	W	Brandenburg Stn	Meade	R-41	3	0	NA
	X	Buck Fork Pond	Todd	F-27	1	1	2
	Y	Bule Knob	Trigg	F-23	1	1	8
	Z	Cadiz East	Trigg	E-21	3	2	254
	Aa	Cave Run Consol	Daviess	O-32	1	0	NA
	Ba	Clark	Christian	G-25,26	7	7	84
	Ca	Claymour	Todd	E-28,29,30	38	34	23
	Da	Cloverport	Breckinridge	Q-35	NA	0	NA
	Ea	Concord Church S	Ohio	L-33	NA	0	NA
	Fa	Crofton	Christian	G-25	2	2	51
	Ga	Doe Run	Meade	R-41,42	65	0	500[3]
	Ha	Duncan Ridge	Logan	F-30	1	0	NA
	Ia	Exie	Green	H-46	1	1	250
	Ja	Horse Branch	Ohio	L-34	1	1	1
	Ka	Lost Run	Breckinridge	O-36	1	1	45
	La	Macedonia E.	Christian	H-23	2	1	80
	Ma	Meadow	Bullitt	S-43	25	0	15-300[4]
			Hardin	R-43			
			Jefferson	S-43,44,T-44			
	Na	Meredith	Grayson	K-39	1	1	20
	Oa	Muldraugh	Meade	R-42	3	3	282
	Pa	Nash	Butler	J-37	11	10	336
			Grayson	J,K-37			
	Qa	Park City	Barren	H-42	NA	0	NA
	Ra	Pleasant Ridge N.W	Daviess	N-30	1	0	NA
	Sa	Post	Grayson	L-37	3	2	53
	Ta	Ready	Grayson	K-37	3	3	149
	Ua	Ready North	Grayson	K-37	2	2	110
	Va	Rockhaven	Meade	R-42,43	45	0	500[3]
	Wa	Shrewsbury	Butler	J-37	70	67	147
			Edmonson	J-37,38			
			Grayson	J,K-37,38			
				K-39			
				L-38			
	Xa	Shakertown	Logan	E-35	1	1	250
	Ya	Sisk School	Hopkins	I-24	1	0	NA
	Za	Unnamed	Caldwell	H-22	1	0	NA
	Ab	Unnamed	Larue	L-46	1	0	NA
	Bb	Unnamed	Logan	F-30	1	0	NA
	Cb	Unnamed	Todd	F-28	1	1	2
	Db	Unnamed	Trigg	E-21	1	0	NA
	Eb	Unnamed	Warren	H-38	1	0	NA
	Fb	West Point	Hardin	R-43	NA	0	NA
	Gb	Windyville	Edmonson	I-38	1	1	30
	Hb	Whittinghill	Grayson	K-36	1	1	5

[1] Number of New Albany Shale wells in the field with IP data

[2] NA = not available

[3] Average open flow for all Meade County gas wells (Jillson, 1931)

[4] From Jillson (1931)

Reference Cited

Jillson, W. R., 1931, Natural Gas in Western Kentucky. Kentucky Geological Survey, Series VI, v. 38, 190 p.

This map was compiled and prepared by the Illinois Basin Consortium (IBC) and is intended for use at the published scale of 1:1,000,000. Federal, state, and local agencies with jurisdiction over public properties and political boundaries may define and describe properties and boundaries in a different manner than that used on this map.

A margin of error is inherent in maps. Thus, a detailed on-the-ground and historical analysis of a single site may result in a revision of the map. This map is not a substitute for an actual survey.

Base modified from U.S. Geological Survey maps of Indiana and Kentucky, scale 1:500,000; Illinois base from ILLIMAP digital files of U.S. Geological Survey 7.5' and 15' quadrangles
Universal Transverse Mercator Projection Reference
Spheroid - Clarke, 1866, UTM zone 16.

MAP SHOWING AVERAGE INITIAL POTENTIAL (IP) FOR NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) GAS FIELDS IN THE ILLINOIS BASIN

Compiled by
Terence Hamilton-Smith, Kentucky Geological Survey
Wesley S. Boberg and Zinta Smidchens, Indiana Geological Survey
Wayne T. Frankie and Donald K. Lumm, Illinois State Geological Survey
1994

Production of this map was funded in part by the Gas Research Institute Contract No. 5090-213-1975 and the Illinois Basin Consortium. The Illinois Basin Consortium consists of the Illinois State Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey. Data compiled through July 1991. Drafted by Kimberly H. Sowder, Indiana Geological Survey. Photography/reprographics by Barbara T. Hill, Indiana Geological Survey.

GAS RESEARCH INSTITUTE 92/0391
ILLINOIS BASIN STUDIES 2

PLATE 7

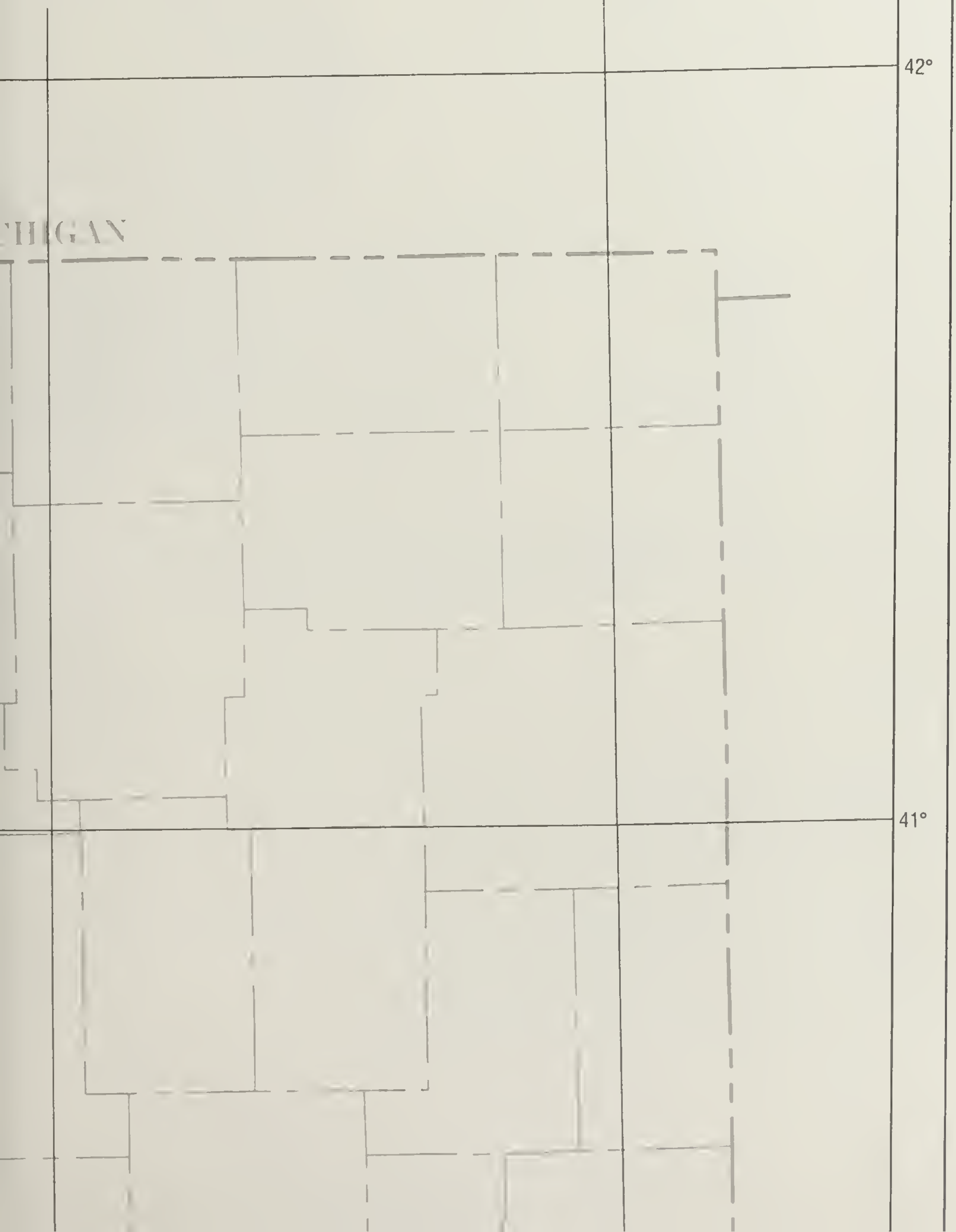
86°

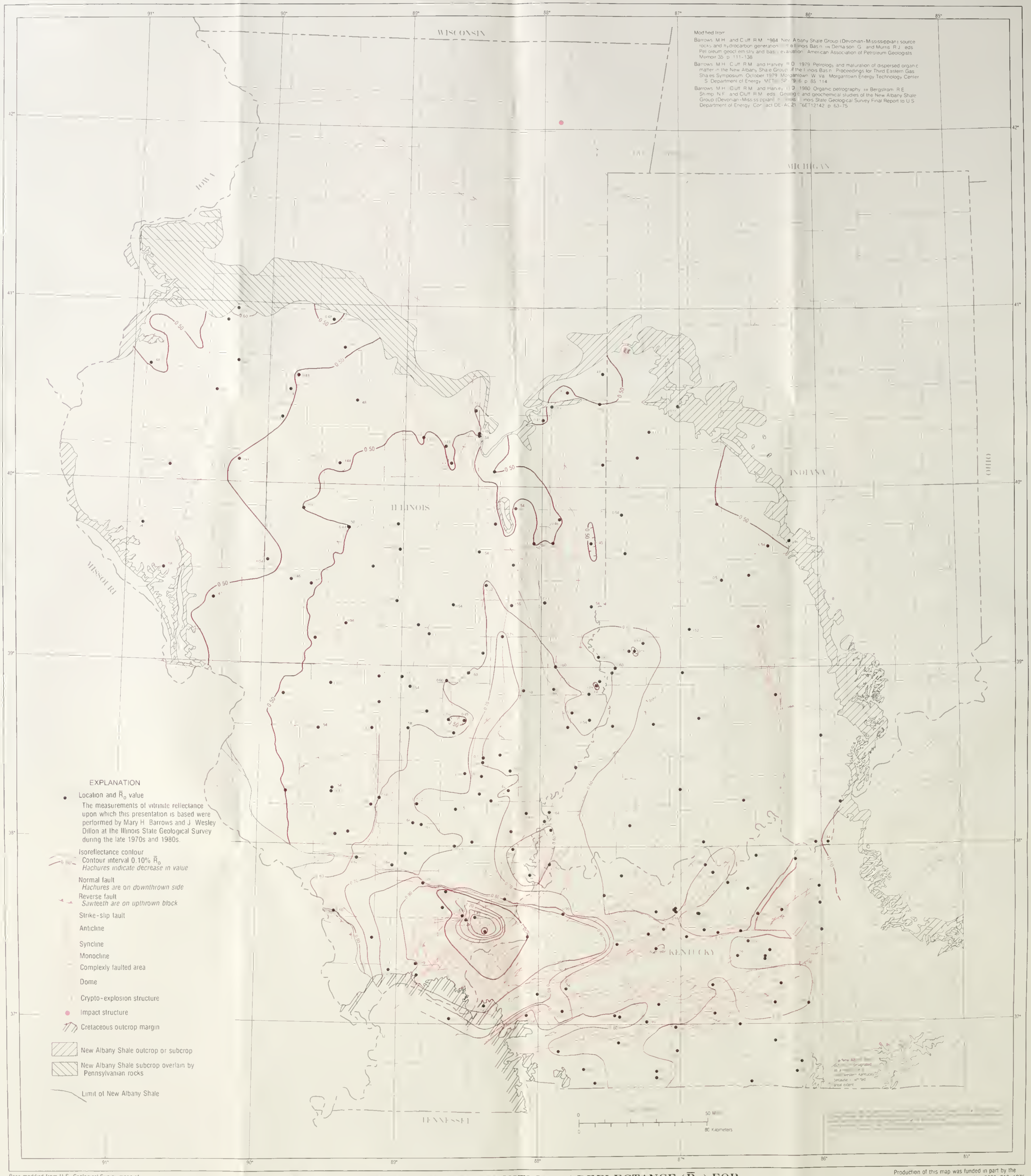
85°

bany Shale Group (Devonian-Mississippian) source
inois Basin, *in* Demaison, G., and Murris, R.J., eds.,
on: American Association of Petroleum Geologists

1979, Petrology and maturation of dispersed organic
he Illinois Basin: Proceedings for Third Eastern Gas
town, W. Va., Morgantown Energy Technology Center,
6, p. 85-114.

1980, Organic petrography, *in* Bergstrom, R.E.,
c and geochemical studies of the New Albany Shale
Illinois State Geological Survey Final Report to U.S.
76ET12142, p. 63-75.





Modified from

Barrows, M. H., and Cluff, R. M., 1984, New Albany Shale Group (Devonian-Mississippian) source rocks and hydrocarbon generation in the Illinois Basin, in Demaison, G., and Murris, R. J., eds., Petroleum geochemistry and basin evaluation: American Association of Petroleum Geologists Memoir 35, p. 111-138.

Barrows, M. H., Cluff, R. M., and Harvey, R. D., 1979, Petrology and maturation of dispersed organic matter in the New Albany Shale Group of the Illinois Basin: Proceedings for Third Eastern Gas Shales Symposium, October 1979, Morgantown, W. Va., Morgantown Energy Technology Center, U. S. Department of Energy, METC/SP-79/6, p. 85-114.

Barrows, M. H., Cluff, R. M., and Harvey, R. D., 1980, Organic petrography, in Bergstrom, R. E., Shimp, N. F., and Cluff, R. M., eds., Geologic and geochemical studies of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Illinois State Geological Survey Final Report to U. S. Department of Energy, Contract DE-AC21-76ET12142, p. 63-75.

EXPLANATION

- ● Location and $\overline{R}_o$ value
  The measurements of vitrinite reflectance upon which this presentation is based were performed by Mary H. Barrows and J. Wesley Dillon at the Illinois State Geological Survey during the late 1970s and 1980s.
- Isoreflectance contour
  Contour interval 0.10% $\overline{R}_o$
  Hachures indicate decrease in value
- Normal fault
  Hachures are on downthrown side
- Reverse fault
  Sawteeth are on upthrown block
- Strike-slip fault
- Anticline
- Syncline
- Monocline
- Complexly faulted area
- Dome
- Crypto-explosion structure
- ● Impact structure
- Cretaceous outcrop margin
- ▨ New Albany Shale outcrop or subcrop
- ▧ New Albany Shale subcrop overlain by Pennsylvanian rocks
- Limit of New Albany Shale

Base modified from U S Geological Survey maps of Indiana and Kentucky scale 1 500,000, Illinois base from ILLIMAP digital files of U S Geological Survey 7 5′ and 15′ quadrangles
Universal Transverse Mercator Projection Reference Spheroid Clarke, 1866, UTM zone 16

MAP SHOWING MEAN RANDOM VITRINITE REFLECTANCE ($\overline{R}_o$) FOR NEW ALBANY SHALE (DEVONIAN AND MISSISSIPPIAN) IN THE ILLINOIS BASIN

Compiled by
John B. Comer, Zinta Snidchens, Paul N. Irwin, and Kimberly H. Sowder, Indiana Geological Survey
Wayne T. Frankie and Donald K. Lumm, Illinois State Geological Survey
Terence Hamilton-Smith, Kentucky Geological Survey
1994

Production of this map was funded in part by the Gas Research Institute Contract No 5090-213-1975 and the Illinois Basin Consortium The Illinois Basin Consortium consists of the Illinois State Geological Survey the Indiana Geological Survey, and the Kentucky Geological Survey Data compiled through July 1991 Drafted by Kimberly H Sowder Indiana Geological Survey Photography/reprographics by Barbara T Hill, Indiana Geological Survey

Headquarters
Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631-3562
312/399-8100

Washington Operations
Gas Research Institute
1331 Pennsylvania Avenue, N.W.
Suite 730 North
Washington, D.C. 20004-1703
202/662-8989

The Illinois Basin Studies is a publication series of the Illinois Basin Consortium and is alternately published by the Illinois State Geological Survey. the Indiana Geological Survey, and the Kentucky Geological Survey. This publication is available from the publication sales offices of the three organizations.

Illinois State Geological Survey
Natural Resources Building
615 East Peabody Drive
Champaign, IL 61820-6964
217/333-4747

Indiana Geological Survey
611 North Walnut Grove
Bloomington, IN 47405-2208
812/855-7636

Kentucky Geological Survey
228 Mining and Mineral Resources Building
University of Kentucky
Lexington, KY 40506-0107
606/257-5500